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IS DISTANCE DEAD? FACE-TO-FACE COMMUNICATION AND PRODUCTIVITY IN TEAMS

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JEL Classification: D23, M11

Keywords: N/A

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Is Distance Dead?
Face-to-Face Communication and Productivity in Teams

(Version 6) [*]

Diego Battiston[†], Jordi Blanes i Vidal[‡] and Tom Kirchmaier[§]

March 15, 2017

Abstract

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Keywords: Teamwork, Face-to-Face Communication, Distance, Organisations.

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1 Introduction

To function effectively, organisations rely on the timely and accurate internal communication of information (Hayek 1945, Arrow 1974). Over time, advances in telecommunication and information technologies have allowed organisations and teams to be more geographically dispersed (Forman and van Zeebroeck 2012, Freeman et al., 2014). This trend has prompted some scholars and commentators to herald the 'death of distance' (Cairncross 2001, Friedman 2005), whereby organisations fully fragment geographically[1]. A symptom of this fragmentation is the offshoring of business support services such as customer services, credit bureaus, and telephone call centres (Jensen et al., 2005). Another manifestation is the growing trend in working from home practices (Mateyka et al. 2012, Bloom et al. 2015).

Many have argued instead that face-to-face interactions remain crucial in the new technological environment (Gaspar and Glaeser 1998, Storper and Venables 2004). The geographical clustering of high skilled creative industries in expensive locations has been interpreted as prima facie evidence in support of this notion (Glaeser, 2014). Reports of global technology firms forcing their engineers to work alongside each other (Reses 2013, Zuckerberg 2015) seem to provide additional, if indirect, evidence. Despite this, very little is known about the extent to which the ability to communicate in person increases the productivity of information-intensive teams. For instance, we do not know how quickly productivitiy decays with physical distance in these settings. Little is also known about how the benefits of co-location may depend on the urgency and informational complexity of the issues facing the organisation, on the homogeneity and stability of the workforce, and on the general pressures in the working environment.

Understanding these issues would allow for nuanced predictions of the circumstances in which communication technologies can substitute or complement human communication. For instance, do we expect face-to-face communication to be important in helping to solve non-routine problems? Will very urgent decisions (or decisions taken under a lot of pressure) be automated in the future? As societies grapple with the disruptive consequences of technological change, a better understanding of these questions would permit us to prepare

[1]The following quote by Nandan Nilekani, the founder of Infosys, is instructive: '(Communication technologies) created a platform where intellectual work, intellectual capital, could be delivered from anywhere. It could be disaggregated, delivered, distributed, produced and put back together again - and this gave a whole new degree of freedom to the way we do work, especially work of an intellectual nature.' Paradoxically, this insight was provided by Nilekani to Thomas Friedman through a *personal conversation*, when the latter flew to Bangalore to interview the former (Friedman, 2005).

for and respond to these trends. From a policy perspective, it would also be valuable to managers searching for the optimal organisation of their personnel and activities.

Unfortunately, tackling these questions is empirically challenging. In addition to the well-known difficulty of measuring the internal operations of organisations, an appropriate setting must be found with sufficient richness in the composition of teams, the nature of the tasks or products assigned to them and the proximity between co-workers. Even if these challenges are overcome, researchers face the obstacle that the geographical configuration of organisations is often the result of an efficiency-maximising decision process, prompting endogeneity concerns.

This Study We exploit a natural experiment to provide evidence on the relation between distance, communication and productivity in a large public sector organisation: the branch in charge of answering 999 calls and allocating officers to incidents in the Greater Manchester Police. An incoming call is answered by a *call handler*, who describes the incident in the internal computer system. When the handler officially creates the incident, its details are available to the *radio operator* responsible for the neighbourhood where the incident occurred. The radio operator then allocates a police officer on the basis of incident characteristics and officer availability. The main measure of performance available to the organisation is the time that it takes for the operator to allocate an officer[2]. Unfortunately, delays often result from the radio operator's need to gather additional information. One way in which she can do this is by communicating with the call handler electronically or in person.

We exploit the fact that handlers and operators are spread across four rooms, each in a separate part of Manchester. Each room contains the radio operators responsible for the surrounding neighbourhoods, as well as a subset of the call handlers, who can take calls from anywhere in Manchester. This arrangement implies that, for some incidents, an operator reads the information inputted in the system by a handler located in the same room. For other incidents, the information will instead have been entered by a handler based in another location. An important consequence of co-location is that it allows the two teammates, handler and operator, to communicate face-to-face if they wish to do so. We argue, and show with a set of balancing tests, that the computerised queuing system matching incoming calls to newly available handlers creates exogenous variation in the co-

[2]We describe this measure in detail in Section 2. There, we also list its advantages and potential limitations and explain why the organisation assigned high importance to this measure during our sample period.

location of handler and operator.

Our setting is ideal to measure when and how proximity between teammates allows for better transmission of information. In addition to exploiting the exogeneity of this proximity, we can take advantage of the fact that our setting generates substantial variation in the individual composition of teams, the types of tasks that each team is assigned to, and the conditions under which these teams operate. The availability of a meaningful performance variable at the incident level permits the measurement of the benefits of co-location, under different scenarios. By leveraging information on the flow of incoming tasks we are also able to determine whether face-to-face communication has costs for the organisation, in addition to benefits.

Results We find that allocation time is 2% faster when handler and operator work in the same room. An important consequence of this faster response is that it decreases the likelihood that the operator misses the country-wide target for a maximum allocation time - a metric by which police forces are evaluated by the UK Home Office. We also show that proximity within the room is important - the effect of co-location is 4% when handler and operator are sitting very close together.

To establish face-to-face communication as the primary explanatory mechanism, we undertake a series of tests. Firstly, we show that allocation time is lower when *the same pair of workers* are sitting inside the room closer together. This finding rules out unobservable characteristics in the match between handler and operator (correlated with co-location) as the main mechanism behind the baseline findings. We provide additional evidence in this respect with a placebo test that exploits an organisational restructure that altered the regular workplaces of handlers and operators.

Secondly, we show that there is no evidence of handler and operator assigning more importance to co-located incidents. This alternative mechanism could be due to visual peer pressure or a psychological effect triggered by a co-located teammate. By using several proxies, we show that the quality of the handler's *electronic* communication does not appear to be higher when a co-located co-worker will be reading the incident's description. We also find that operators do not assign higher priority to co-located incidents, and at the expense of other contemporaneous incidents.

We further distinguish between alternative mechanisms by examining the behaviour of the handler *after* officially creating the incident. Under the face-to-face communication mechanism, the handler spends time talking to the operator, which temporarily prevents her from being available to take new calls. Alternative mechanisms, such as better electronic communication on the handler's part or higher effort by the operator, do not naturally have that prediction. We show that handlers spend more time 'unavailable' to take new calls following the creation of co-located incidents, which provides indirect evidence that they are communicating with the operator in these incidents.

We provide two additional sets of results. Firstly, we establish that being able to communicate face-to-face has a higher effect for: (a) more urgent and information-intensive incidents, (b) in conditions of higher operator workload, (c) when the teammates are more homogeneous (in terms of age and gender), and (d) when the teammates have worked together more often in the past. Secondly, we highlight and compute the opportunity costs of face-to-face communication. Every second that the handler spends talking to the operator about a recently created incident cannot be devoted to answering new calls. We show that, in our setting, the number of incoming calls per on duty handler is relatively low, which means that handlers sometimes are waiting for, rather than answering, calls. This makes the opportunity cost of face-to-face communication relatively low and the net benefit positive. We argue that, if the organisational slack was lower and face-to-face communication took longer, the net benefit could be very different.

Contribution This paper provides, we believe, the first detailed causal evidence on the relation between proximity, communication and productivity inside organisations. Of course, the study involves a particular setting and production technology. As such, the implications are stronger for high pressure environments such as the healthcare professionals assessing and treating patients in emergency rooms, or the frontline staff and their supervisors in air traffic control, the military, and other time-critical settings.

More generally, we also believe that the insights on the contingent value of face-to-face communication have broader applicability. The finding that the urgency and information-intensity of tasks are important determinants of this value are both intuitive and of general relevance. Equally significant is the result that geographical and social distance are strategic complements in communication-intensive production settings. We outline in the conclusion a number of policy prescriptions based on this finding.

Lastly, we are the first to provide a measure of the opportunity cost of the time spent engaging in face-to-face communication. Computing these measures would be impossible without the high granularity of the dataset, in particular with regards to the ability to follow workers' behaviour and the inflow of tasks in real time. One lesson that is of likely general applicability is that the cost of communication depends on the alternative use of the worker's time, and therefore on the amount of slack in the organisation.

Related Literature This paper connects to three strands of literature. A large body of work examines the relation between geographical proximity, assumed to facilitate face-to-face interactions, and the diffusion and generation of knowledge (Jaffe et al. 1993, Thompson and Fox-Kean 2005). A challenge here is to disentangle geographical distance from other factors, such as knowledge or social distance, correlated with it, but recent papers by Boudreau, et al. (2014), Catalini (2016) and Catalini et al. (2016) make substantial progress in this respect. While this literature is mainly concerned with forming new teams in order to create new knowledge, our setting is more similar to the problem-solving organisations of Radner (1993) or Garicano (2000). An advantage of our paper is that teams and incidents are exogenously formed, which allows us to concentrate on how face-to-face communication enables the resolution of the issues facing the organisation.

The second strand of the literature is on teamwork. Most empirical work here has been on the measurement of team-specific human capital (Hayes et al. 2006, Bartel et al. 2014, Jaravel et al. 2016), or on the effects of team-based incentives in settings where production is individual (Hamilton et al. 2003, Bandiera et al. 2013). Our main distinction with this work is the emphasis on communication effectiveness in an environment of team, rather than individual, production[3]. The closest parallel here is probably Boning et al. (2007) panel-data study on the incentives of problem-solving teams. By exploiting a natural experiment and measuring the production process very precisely, we identify the costs and benefits of a particular channel through which 'problem-solving teams' solve problems.

The focus on how human (i.e. face-to-face) communication contributes to the production process creates a link with studies examining the impact of new technologies on organisations and workers (Bresnahan et al. 2002, Autor et al. 2003, Acemoglu and Autor 2011, Bloom et al. 2014). Our paper strongly complements Bloom et al. (2015) finding that working from home increased productivity in a Chinese call centre. The contrast with our result that co-location is more efficient is likely the result of the many differences between

[3]Mas and Moretti (2009) and Chan (2016) study social incentives when workers produce largely individually but are jointly responsible for a wider outcome, such as the waiting times of incoming customers. This introduces a joint production component to their effort decisions.

the two settings. A very important one is probably the complexity of the production process. While the simple individual production of Bloom et al. (2015) can be easily monitored and co-ordinated remotely, we show that, in organisations requiring tight co-ordination between colleagues, working in the same place may instead be more effective[4]. We provide evidence in this respect by showing that the benefits of co-location are contingent on the information-intensity of the incident.

Plan We describe the institutional setting in Section 2. We introduce the data and the empirical strategy in Section 3. We present the main results of the paper in Section 4. In Section 5, we provide evidence in support of the face-to-face communication mechanism. Section 6 explores the heterogeneity of the main results. In Section 7, we provide a cost-benefit analysis of the face-to-face communication effect. Section 8 concludes.

2 Institutional Setting

We exploit a natural experiment in the Operational Communications Branch (OCB) of the Greater Manchester Police (GMP). The OCB is the unit in charge of answering 999 calls from members of the public and managing the allocation of officers to the corresponding incidents. Figure 1 provides a simplified visualisation of this production process.

Call Handler Emergency calls requesting the police are allocated to call handlers using a standard computerised queuing system. A result of the system is that any handler can respond to calls from any Manchester location.

The handler questions the caller, assigns an opening code and a grade level, and records any information deemed relevant. The grade level can range from one to three and, very coarsely, determines the official urgency of an incident. The opening code describes, horizontally and at a fairly detailed level, the type of issue that the incident relates to (neighbour dispute, disturbance in licensed premises, etc.). The description of the incident will include information on the individuals involved, their states of mind, the existence of prior history between these individuals and the likelihood of further incidents in the near future[5].

[4]One way to interpret face-to-face communication is as an efficient channel to coordinate the information that a receiver needs with the messages that a sender sends.

[5]The language used in these descriptions is highly efficient, as it includes a large number of official and unofficial abbreviations for features of incidents that appear repeatedly. For instance, official abbreviations include A/ABAN (apparently abandoned) and NFA (no fixed abode). Unofficial but widely used

All the information above is recorded in GMPICS, a specialised IT package used throughout the GMP to create, record and manage incidents[6]. The handler ticks a box in GMPICS to officially create the incident, and then indicates her status as 'not ready' (which allows the handler, among other things, to step away from his desk), or instead 'ready to receive new calls'. Under the 'ready' status, a call can arrive at any point and must immediately be answered by the handler.

Radio Operator When an incident is created, it immediately appears on the computer screen of the radio operator overseeing the Manchester subdivision where the incident occurred. The allocation of incidents to radio operators is deterministic, since at any point in time there is only a single operator in charge of a specific subdivision (a corollary of this is that handlers do not decide to which operator they assign an incident). Radio operators are in charge of processing the information inputted by the handler and allocating police officers to incidents, on the basis of incident characteristics and officer availability.

Lacking a direct link with the caller, the radio operator has to rely on the information recorded by the handler in GMPICS. It is, however, often the case that additional information is needed before an officer can be allocated. For instance, written descriptions of incidents are regarded by radio operators as lacking sufficient emotional content, which makes it harder to understand the state of mind of the victim and the impact that the incident has had on it. Similarly, a full characterisation of the physical surroundings where the incident occurred, or of the complex relationships between the people involved are often difficult to communicate in writing. A complete picture of the incident is often necessary to efficiently match incidents with officers, advise the attending officer of important details that she may find at the scene, or even understand the level of priority that the incident merits[7].

The additional information can be acquired by conducting targeted searches on specific

abbreviations include XXX (very drunk). Despite this, the written descriptions inevitably fail to perfectly communicate the full richness of the information gathered by the call handler.

[6]Our personal conversations with multiple handlers, radio operators and their supervisors indicate that GMPICS is widely regarded as an efficient, if relatively outmoded, system. GMPICS was developed in-house and incrementally over more than two decades. OCB staff receive extensive training and accumulate considerable expertise in its use.

[7]Regarding the optimal matching between incidents and officers, note for instance that some incidents can be responded alternatively by sworn police officers or by PCSOs (police community support officers) and the likelihood that the more extensive legal powers and expertise of police officers may be needed is decision-relevant information. Similarly, incidents involving vulnerable individuals require officers with specialist training, which makes it critical to understand the condition of the caller and other individuals affected. More generally, certain officers are particularly well-suited to dealing with specific types of incidents or individuals.

individuals or addresses in the GMP databases, asking the call handler or contacting the initial caller directly. Often, the allocation of an officer will be delayed until the radio operator can gather this information.

Teamwork In this paper our definition of a team comprises the combination of the call handler and the radio operator. While officially equal in rank, the positions of call handler and radio operator are associated with different status within the OCB. This stems from the fact that the job of radio operator is both more complex and more stressful, as it involves carrying out a variety of tasks in parallel and bearing the ultimate responsibility for the outcomes of incidents. The decision-making authority of radio operators is also wider. For instance, they can overrule the code and grade allocated by the handler (although this is in practice rare). Accordingly, radio operators earn a higher salary and have on average more experience in the OCB. Many in fact transferred into radio operations from the call handling desk, a move widely seen in the organisation as a promotion.

Face-to-Face Communication When a radio operator regards the electronic description of an incident insufficient, an efficient and fast way to gather this information is to ask the handler in person[8]. More common in our setting (according to our sources), handlers often decide to complement the written description with additional information delivered face-to-face. When handler and operator are communicating in person, the handler will typically need to be in 'not ready' status, as she may otherwise be forced to abruptly end the conversation when a new call arrives.

Members of the OCB attach several advantages to face-to-face communication: firstly, it is a highly efficient channel, in that it allows for rapid, short exchanges that provide immediate feedback to both teammates. Secondly, non-verbal cues can help to communicate fuzzy concepts that in writing would require lengthy descriptions. Thirdly, it is a more natural vehicle for the use of colloquialisms that can succinctly and effectively communicate characteristics of an incident including the physical or mental condition of the individuals involved. For a variety of reasons (including the possibility of future audits of the official GMPICS descriptions) these colloquialisms are less likely to be used in written communication.

[8]Communicating on the phone is theoretically possible but in practice unlikely, as a handler in status 'ready to take new calls' cannot be contacted on the phone without first alerting the handler's supervisor. On the other hand, a handler can easily switch status from 'ready' to 'not ready' if an operator approaches in person with the need to clarify some doubt.

Co-Location In the period between November 2009 and January 2012, OCB staff were spread across four buildings or 'rooms', each in a different part of Manchester: Claytonbrook, Leigh, Tameside and Trafford. Every room accommodated the radio operators overseeing the surrounding subdivisions (Figure 2 displays the areas overseen from each of the four locations). As discussed earlier, call handlers were not geographically specialised. However, for historical reasons they were also dispersed across the four locations. This assignment meant that radio operators would sometimes be reading the descriptions of incidents created by same room handlers, while on other occasions the handlers were based in a different part of Manchester.

In January 2012, a major reorganisation of the OCB reassigned all handlers to a single location (Trafford), while radio operators were divided between Claytonbrook and Tameside. This put an end to the natural experiment that we study here.

Measures of Performance As is the case with other public sector organisations (Dewatripont et al., 1999), objectives in the GMP are multifaceted and often vague. The prevention of harm or damage to property, the satisfaction and reassurance of the public, and the application of sufficient but proportionate force are all important objectives that escape precise measurement. Capturing every one of these objectives with explicit measures of performance is therefore an impossible task. Our first measure of performance is the allocation time of an incident: the time elapsed between its creation by the call handler and the allocation of an officer by the radio operator. We also study the effect of distance on response time: the time between creation and the officer reaching an incident's scene[9].

The two measures that we use are undoubtedly partial. They do not capture, for instance, any notion of whether the 'right' officer was allocated to an incident, or whether the attending officer was in possession of all the relevant information prior to arrival. They also do not indicate whether or not excessive or insufficient resources were allocated to resolve an incident. The measures, however, have features that make them particularly appropriate for this study. Firstly, they are available at the incident level, the same level at which the variation in distance occurs in our study. As long as the improvement in allocation and

[9]These two measures are strongly correlated, since response time is equal to allocation time plus the officer's travel time. It is worth noting that better information on the part of the radio operator could affect travel time also. Imagine, for instance, a radio operator deciding whether to allocate the closest officer, or an officer with a specialised skill. Better information could reveal that the incident does not require the specialised skill, and that the officer with the shorter travel time can be safely allocated.

response times that we document in Section 4 is not accompanied by a deterioration of unobserved dimensions of performance, physical proximity between handler and operator will have lead to higher organisational efficiency.

Secondly and most importantly, they are critical measures for the organisation. Survey evidence suggests that response time is one of the most important determinants of citizens' satisfaction with their police forces (Dodd and Simmons 2002/03). Furthermore, in 2008 the UK Home Office established nation-wide numerical targets regarding allocation and response times[10]. While these targets were nominally scrapped in June 2010, police forces continued to regard them as objectives and to believe that they were being informally evaluated on this basis (Curtis, 2015). There is substantial evidence that the leadership of the GMP internalised the need for minimising these times. One example can be found in the GMP Incident Response Policy manual April 2011. Only one tactical performance monitoring is reflected in the manual: allocation and response times. In particular, the manual indicates that[11]:

> *The OCB will produce daily reports regarding graded response performance. This will include the % of incidents resourced within target and the % attended within target for each division. This will enable ongoing analysis of the accuracy of the resource management of that BCU.*

3 Empirical Strategy

In this section we present and discuss the dataset and main variables of the paper. We also first explain the empirical strategy, and then justify it with a set of balancing tests. Establishing a causal effect between proximity and performance is not an easy task. In addition to exploiting the idiosyncratic allocation of incidents to handlers, which we outline in this section, we will need to consider the possibility that distance represents a proxy

[10]For Grade 1 crimes, for instance, these targets were for a maximum of two minutes and fifteen minutes for allocation time and response time, respectively. The equivalent targets for Grade 2 (respectively Grade 3) were 20 and 60 minutes (respectively 120 and 240 minutes).

[11]Additional examples include the following. The launching in April 2010 of a website where the public could access up-to-date statistics on response times, separately for each of the twelve divisions (Pilling, 2010). Secondly, the fact that throughout our sample period every report by the GMP to the Manchester City Council Citizenship and Inclusion Overview and Scrutiny Committee provided detailed statistics on response times and, if these were deemed unsatisfactory, a list of reasons for the failure. Lastly, information on response times was also frequently discussed in the reports produced by the HMIC (the central body that in the UK regulates and monitors police forces). For an example, see HMIC (2012).

for unobserved characteristics of the handler, or handler/operator pair. We postpone the discussion of these confounding effects, together with the tests that we use to evaluate them empirically, to Section 4.

Dataset Our baseline dataset contains every incident reported through the phone to the GMP between November 2009 and December 2011. We restrict our attention to incidents where the handler allocated the call a grade below or equal to three, therefore transferring responsibility to a radio operator rather than to a divisional commander. For every incident we observe, among others, the allocation and response time, the location of the incident, the grade and (horizontal) opening code, the identity of the call handler and radio operator, and the desk position from which the handler took the call. The dataset was made available to us under a strict confidentiality agreement.

Table 1 provides basic summary statistics for the main variables in our study. Note first that our sample size is very large, as it includes close to one million incidents. In around one in four observations the handler and operator are in the same room. The performance variables are highly right-skewed. For response, for instance, the median time is 19 minutes, while the average time is more than four times larger[12].

We find that there is considerable gender and age variation among handlers and operators. Consistently with our earlier discussion of the differences in status, operators are significantly older than handlers. They are also more likely to be female, likely the result of females being more likely to regard the OCB as a long-term career choice.

Intuition of Empirical Strategy The computerised queuing system allocating calls to handlers works as follows. As calls come in, they join the back of a call queue. The system matches the call at the front of the queue with the next handler that becomes available. If the call queue is empty and several handlers start to become available, they form their own queue. The system then matches the handler at the front of the handler queue with the next incoming call. The system creates exogenous variation in the co-location of the handler and operator involved in an incident. We visualise this notion in Figures 3A and 3B where, for simplicity, we assume that there are only two locations (Trafford and Leigh), rather than

[12]The maximum value is more than 15 days, likely the result of some error in the classification of the incident. The fact that the left hand side variables in our regressions are in logarithmic form should dampen the effect of outlying observations. Nevertheless, in Appendix Table A10 we show that our baseline estimates are robust to the exclusion of these outliers.

four.

Assume that, within a relatively narrow time horizon, two calls (one from Trafford, one from Leigh) reach the queuing system, and that two handlers (one based in Trafford, the other in Leigh) become available. The exact timing at which handlers become available is the result of a large number of factors, including the length of their previous calls, the time at which the calls started, the existence and length of 'not ready' periods etc. Similarly, the exact order at which the calls arrive is the result of many factors, including the times at which the incidents occurred, the delay in dialling 999 and the further delay in opting for a police service and being transferred to the GMP. These factors are arguably orthogonal to the factors determining the order at which handlers become available. It follows that two handlers that are on duty during the same time period should be equally likely to be the one assigned to an incoming call. If, as in Figure 3A, the handlers are assigned calls from a subdivision that their room oversees, they will be co-located with the radio operators with whom they have to communicate electronically. For arguably exogenous reasons, they may instead be assigned a call (and have to communicate with an operator) from a different area of Manchester. We capture this variation with the dummy variable *SameRoom*, which is the main independent variable in our study.

We have just argued that, conditional of the exact time period at which a call arrives, on duty handlers should be equally likely to be assigned that call. In practice, some rooms (for instance Trafford) were bigger than others (e.g. Leigh) and therefore contain a larger number of handlers. This implies that the likelihood of $SameRoom = 1$ will be mechanically higher if the call originates in a Trafford neighbourhood, relative to a Leigh neighborhood. Calls originating from Trafford and Leigh may also have different characteristics, which could independently affect their average allocation and response times. Therefore, our claim regarding the exogeneity of the variable *SameRoom* is only conditional on hour (i.e. year X month X day X hour of day) and (handler and operator) room fixed effects[13].

Estimating Equation Our baseline estimating equation is:

$$y_i = \beta SameRoom_{j(i)k(i)} + \theta_{t(i)} + \lambda_{j(i)} + \mu_{k(i)} + \pi_{g(i)} + \gamma_{h(i)} + \mathbf{X_i} + \epsilon_i \tag{1}$$

[13]In most regressions, we use hour fixed effects to condition for the exact time period at which a call arrives. Our findings are qualitative unchanged if we instead control for the half-hour or quarter-hour period (see, for instance, Appendix Table A7).

where y_i is a measure of OCB performance for incident i. Throughout our paper, allocation and response times are measured in log form, both for ease of interpretation of the coefficients and in the presence of right-skewness to minimise the effect of outlying observations. Consistently with our earlier discussion, we control for $\theta_{t(i)}$ (the fixed effect for the hour t at which the incident arrived) and $\lambda_{j(i)}$ and $\mu_{k(i)}$ (the fixed effects for the rooms j and k from which the incident was handled and dispatched). Our main independent variable of interest is the dummy $SameRoom_{j(i)k(i)}$, which takes value 1 when rooms j and k coincide.

We also control in our baseline specification for $\pi_{g(i)}$ and $\gamma_{h(i)}$ (the fixed effects for the individual handler g and operator h assigned to the incident) and by other incident characteristics (such as the assigned grade) included in the vector $\mathbf{X_i}$. These latter controls are not essential for identification, but should contribute to the reduction of the standard errors. We cluster these standard errors at the operator room and year/month level. In Appendix Tables A1 and A2 we show that the baseline findings are robust to the inclusion or exclusion of additional controls and to alternative clustering choices.

Balancing Tests Our first set of tests examines the balance of incident (grade, location of the incident scene), worker (gender, age, location of the desk, current workload) and room time-varying (measures of current average workload) variables across the co-location of handler and operator. To perform these tests, we regress each variable on *SameRoom*, after controlling for hour and room fixed effects. These standard balance regressions are essentially variations of equation (1), with incident characteristics on the left hand side and without the right hand side non-essential controls. To ease interpretation, non-binary dependent variables are standardised.

The results in Figure 4, where we label each row in the left axis by the regression dependent variable, plot the estimated confidence intervals of *SameRoom*. To illustrate the need for our empirical strategy, we report for every variable the estimates of two regressions: with and without the hour and room controls. We find first that *SameRoom* is (unconditionally) strongly correlated with incident characteristics: the estimates are large and most are statistically significant. The introduction of the hour and room controls, however, greatly decreases both the standard errors and the estimates, which then become extremely small in magnitude. For instance, among the non-binary variables all the estimated coefficients imply an effect of *SameRoom* lower than .005 standard deviations of the dependent variable[14].

[14] Appendix Figure A1 shows that it is the room controls that are critical to the empirical strategy. Failing

We also find that, after including the hour and room controls, only two of the sixteen coefficients are statistically different from zero at the 5% level. Although higher than one-in-twenty, we regard this ratio as remarkably low considering that the regressions are run on close to one million observations. Note further that the significant coefficient associated with the Grade 1 regression is both small in magnitude and *negative*, suggesting that same room incidents are more likely to be allocated a low priority by the handler, and should therefore have *higher* allocation and response times.

The variables in Figure 4 do not include the incident opening code, an important determinant of allocation and response times. The opening code is captured empirically by a large set of dummy variables that are mechanically correlated with each other, which creates a mechanical correlation on the results of balance regressions based on equation (1). We therefore switch the dependent and independent variables, and estimate:

$$SameRoom_{j(i)k(i)} = \alpha_i + \theta_{t(i)} + \lambda_{j(i)} + \mu_{k(i)} + \epsilon_i \tag{2}$$

where α_i are the fixed effects for the incident opening code. We find that the F-statistic of joint significance of these effects is 1.15 (P-value = .30), suggesting that *SameRoom* and the opening code dummies are conditionally uncorrelated. Overall, we interpret the results of estimating (2) and the regressions of Figure 4 as consistent with our assumption that co-location between the handler and operator of an incident is conditionally orthogonal to incident, handler, operator and room time-varying characteristics.

4 Main Results

In this section we present and interpret the baseline results of the paper. We then use a number of tests to confirm that these estimates can indeed be interpreted as the causal effect of distance on performance, rather than the result of distance being a proxy for unobserved determinants of allocation and response time. The section concludes with an investigation of potential spillovers onto other (contemporaneous) incidents assigned to the radio operator.

Baseline Estimates Our baseline regressions are variations of equation (1). In the first two columns of Table 2 we find that allocation and response time are approximately 2% faster on average when handler and operator are located in the same room. At the mean

to control for the hour of the incident does not lead to a stronger correlation between *SameRoom* and the incident characteristics.

(respectively, median) of the independent variable, this 2% translates into 76 seconds (respectively, 5.4 seconds) saved in terms of allocation time. For response time these savings are of 104 and 20 seconds, evaluated at the mean and median respectively.

We also investigate whether these times are 'on target'. Throughout our sample period, it was an explicit objective of the UK Home Office that allocation and response times should typically be below certain levels[15]. As a result, the GMP recorded information on whether the target maximum time was exceeded for an incident. We use these dummies as dependent variables and find in Columns 3 and 4 that the likelihood of being on target is higher when $SameRoom = 1$. For instance, the coefficient in Column 3 indicates that the likelihood of missing the allocation target decreases by .4 percentage points (around 2% of the mean of .25), when handler and operator are co-located.

Lastly, we find in Column 5 no evidence of co-location affecting the likelihood that incidents classified as crimes are cleared by the GMP[16].

Estimates by Distance Inside the Room Table 2 has established that co-location of handler and operator is associated with higher performance, relative to them working in rooms in separate areas of Manchester. We now investigate whether performance improves as distance decreases *even when handler and operator are already working in the same room.* In addition to providing richer evidence on the functional form of the relation between distance and teamwork performance, within-room variation allows the introduction of handler/operator pair fixed effects in the regression. We argue in the next subsection that the introduction of these controls strengthens the credibility of our claim regarding the causal interpretation of the estimates.

The assignment of desks to workers was as follows. Inside a room, a fixed desk would be earmarked for the radio operator overseeing a specific subdivision. Handlers, on the other hand, were free to work from any remaining and available desk. To measure the within-

[15]See Section 2 for details about these targets. The fact that the 'on target' dummies are affected by co-location confirms that the results are not disproportionately due to extreme values of the allocation and response time distributions. It also reinforces the relevance of the results from a policy perspective.

[16]The absence of a statistically significant effect on the likelihood of clearing the crime may be due to the fact that our sample size is much smaller in this regression, since only around 16% of incidents are crimes. Nevertheless, it is somewhat surprising given the findings of Blanes i Vidal and Kirchmaier (2016) that a faster response time increases the likelihood of clearing the crime. In that paper, the identification strategy exploits discontinuities in distance across locations next to each other but on different sides of division boundaries. In the current paper, co-location between handler and operator would likely not be a valid instrument for response time. The exclusion restriction is unlikely to be satisfied because co-location could affect clearance likelihood through many channels in addition to faster response times.

room distance between desks, we use yearly-updated floorplans of the four OCB rooms (see Figure 5 for an example)[17]. We set distance to zero if handler and operator are not in the same room, and add the interaction of distance and the same room variable to our baseline specification.

We provide two types of evidence. In Table 3 distance is measured parametrically, in logs. In Figure 6 we instead split distance into four categories of approximately equal sample size, and plot the interactions of *SameRoom* with these dummies. The estimates from both specifications indicate that teammates that sit closer together are more productive. In the parametric estimation, a 10% decrease in within-room distance is associated with a 2.6% increase in the effect of *SameRoom* on allocation time. The non-parametric evidence is perhaps more informative. We find that incidents assigned to workers separated by a distance lower than 2 (e.g. diagonally adjacent desks at most) are on average allocated and responded 4% faster. The effect decreases monotonically with distance and becomes zero when handler and operator are separated by a distance higher than 4[18].

A question evident in Figure 6 is why should the benefits of proximity be so local in our context, to the point where being in the other side of the room is equivalent to being on the other side of Manchester. While we cannot provide a definitive answer, our conversations with GMP staff have pointed to the fact that some supervisors are less than encouraging regarding the communication between handlers and operators, as they view these conversations as distractions from the handlers' main role. A consequence of these attitudes is that handlers are often unwilling to stand out too much by stepping far away from their desks.

Establishing a Causal Interpretation Our preferred interpretation of the findings in Table 2 is that: (a) being physically closer allows teammates to communicate face-to-face, and (b) in settings where information is complex and must be processed relatively quickly,

[17] The floorplans are unfortunately not to scale, which prevents us from measuring distance in metric units and is likely to introduce measurement error in the within-room distance variable. Instead, desks are depicted in the floorplans in a matrix (x, y) format. Our measure is therefore the euclidean distance between desks inside this matrix. $D = \sqrt{[(y_{RO} - y_H)^2 + (x_{RO} - x_H)^2]}$, where y_{RO} is the position of the radio operator along the row dimension and the other coordinates are defined accordingly. As an example, two adjacent desks in the same row or column are at a distance of one, while the distance between two diagonally-adjacent desks is $\sqrt{2} = 1.4$.

[18] To interpret this, note that two desks that are three positions apart along both the row and the column dimension are separated by an euclidean distance of 4.2. Two desks separated by three positions along one dimension and two positions along the other are at a distance of 3.6.

this additional communication channel is performance-improving. An alternative interpretation is that call handlers may be better informed or motivated to deal with incidents originating in the geographical area that surrounds their workplace. To understand this potential confounding effect, note in Figures 2 and 3A that $SameRoom = 1$ when a handler based in a location is allocated an incident from the geographical area surrounding that location. If handlers are more effective at dealing with cases that occur closeby, the findings in Table 2 may reflect proximity to the incident scene, rather than to the co-worker.

A second alternative interpretation is that co-location may be a proxy for some unobserved dimension of similarity between teammates. In an extreme example, imagine that workers communicate through room-specific language, which makes electronic communication with individuals outside one's room less efficient. This would be the case if, for instance, there are strong local dialects and the workers in a room are drawn from the neighbourhoods surrounding that room. In that case, co-location would represent a proxy for the ease of electronic communication between teammates, as opposed to providing a performance-improving additional communication channel.

In Columns 3 and 4 of Table 3 we find evidence that is inconsistent with the two alternative interpretations above. We add a set of handler/operator *pair* fixed effects to the baseline regressions, and estimate the effect of distance within the room on performance. Because handlers and operators do not typically change workplace, the introduction of pair fixed effects effectively absorbs the same room variable.

We find that *the same pair of workers operating from the same room* are more productive when their desks are closer together. The estimated coefficients are in fact almost identical to those in Columns 1 and 2, without the pair fixed effects. These effects absorb any characteristics of the match between handler and operator (including the match between the handler and the location of the incident). The robustness to their inclusion therefore confirms that it is the location of the handler relative to the operator that causes the estimated Table 2 decreases in allocation and response times.

A second strategy to evaluate the above is to perform a placebo test using the post-2012 information. As we mentioned in Section 2, the 2012 reorganisation of the OCB relocated all the call handlers to Trafford, while the radio operators were split between Claytonbrook and Tameside. Therefore, handlers and operators never shared a room after 2012. Using the information on the workplaces of handlers and operators *just before* the reorganisation, we can construct 'placebo same room' variables taking value one when an incident is allocated to a pair of teammates that used to be co-located[19]. In the estimation of (1) we now interact the same room variable with dummies for each of the five semesters comprising our baseline period (the last semester of 2009 includes only two months, since the data starts in November). We then use the post-2012 data to estimate (1) again, interacting the placebo same room variable with semester dummies. The coefficients are displayed in Figure 7.

We find that the same room variable is essentially zero for every semester of the post-2012 period, while it is negative for most of the baseline period. Note in particular the large difference in the estimates between late 2011 and early 2012. This difference suggests that the same pairs of workers that were able to deliver higher performance when jointly assigned to an incident ceased to do so when they stopped being co-located. The evidence in Figure 7 reinforces the conclusion that it is indeed distance between co-workers, rather than unobservables correlated with distance, that improves allocation and response times[20].

Spillovers to Other (Contemporaneous) Incidents We now investigate the existence of potential spillovers from same room incidents into other contemporaneous incidents. Radio operators typically have open (i.e. yet to be allocated) several incidents at the same time. Theoretically same room incidents can generate both positive and negative spillovers. Positive spillovers will occur, for instance, when the time and effort that the operator saves on a same room incident (as a result of being able to gather information more efficiently) is redistributed to other contemporaneous incidents. Negative spillovers are equally plausible. One potential channel would be operators assigning higher priority to incidents that have been created by co-located handlers. If that was the case, the improvement in performance for same room incidents that we document in Tables 2 and 3 would be, at least partially, at the expense of other contemporaneous incidents, as attention is diverted away from them.

To study whether spillovers are in fact present in our setting we first replicate our baseline specification and use as independent variable of interest the percentage of incidents

[19]Following the reorganisation radio operators remained in their previous roles in terms of the subdivisions for which they dispatched officers. Therefore, a post-2012 handler-operator match continues to capture accurately whether the handler is assigned a case from the geographical area around her pre-2012 workplace.

[20]Interestingly, Figure 7 also suggests that the effect of co-location on productivity may have been increasing over time. In November 2009 a major reorganisation had taken place that created a Manchester-wide handling system and split the roles of handler and operator. Workers may have taken time to adapt to their new roles, and to fully exploit the sources of higher productivity in the new setting. In particular, the coefficients of Figure 7 are consistent with workers learning about the performance-improving potential of co-location over time. We return to this issue in Section 6, where we investigate whether individuals that have worked together on more incidents in the past benefit more from co-location.

assigned to the operator that, in the period surrounding the index incident, are same room incidents. Positive spillovers should lead to a negative coefficient for this variable because, if same room incidents are easier to deal with, a higher share of those will allow for more time and effort being available for the index incident. Negative spillovers would instead imply that valuable attention or resources are diverted away from the index incident when other incidents are handled in the same room, leading to higher allocation and response times, and a positive coefficient in this regression[21].

We find in Table 4 no evidence of either positive or negative spillovers. Given the uncertainty about the time horizon on which spillovers might occur, we calculate the independent variable at the 60, 30, and 15 minutes time horizon. We find in every case that a higher share of same room incidents does not translate into different performance for other contemporaneous incidents.

We perform a second exercise by ordering the incidents assigned to each operator according to the time at which they were created. We then create leads and lags for the four incidents that, for a given operator, immediately precede and follow a same room incident[22]. The estimated coefficients in Figure 8 are inconsistent with the existence of negative spillovers, since none of the lag and lead coefficients is positive and statistically different from zero. One of the eight coefficients is negative, providing at most weak evidence of some positive spillovers. Overall, we interpret Figure 8 as suggesting, consistently with Table 4, that the improvement in performance of same room incidents is neither at the expense nor to the benefit of other contemporaneous incidents.

5 Mechanism

The findings above have established the existence of a causal relation between co-location and performance. Our preferred explanation is that co-location permits face-to-face interactions which communicate relevant details about incidents. In this section we first discuss alternative mechanisms, and then provide evidence that is consistent with the face-to-face communication mechanism but inconsistent with alternative mechanisms.

[21] We use the baseline sample for this exercise, since in principle spillovers could occur both to same room and to non-same room incidents. In Appendix Table A6 we restrict the sample to including only non-same room incidents and find very similar effects.

[22] Because incidents are not dispatched immediately, a same room incident could create spillovers to other incidents that were assigned to the same operator earlier in time.

Alternative Mechanisms The first alternative channel consists of the handler exerting more effort in the transmission of the GMPICS electronic information under co-location. The second alternative channel is similar: the operator might exert more effort in the interpretation of this information, and the subsequent allocation of an officer, for co-located incidents[23].

We can think of two plausible reasons why workers may exert more effort under co-location, even in the absence of face-to-face communication[24]. The first reason would be some type of (silent) psychological effect leading to higher priority assigned to incidents that will be read, or were written, by a same room co-worker. Given the findings in Columns 3 and 4 of Table 3 this effect should of course be dependent on the within-room distance between the co-workers. The second potential reason would be handler and operator exerting visual peer pressure on each other, similarly to the visual pressure among supermarket cashiers identified by Mas and Moretti (2009).

We regard this second reason as very unlikely, in particular with regards to the handler exerting peer pressure on the operator, as several features of the institutional setting are inconsistent with it. Firstly, while handler and operator are 'teammates', they are not actually 'peers'. As discussed in Section 2, operators are both more senior and uniquely responsible for the allocation of the incident, which makes it improbable that they may feel a lot of pressure from handlers. There is in fact little scope for handlers to even be aware of the allocation and response times of the incidents that they created, unless they actively search for them in the GMPICS system. Furthermore, the cognitive and desk-bound activities of the operator are difficult to monitor visually, especially relatively to manual tasks like supermarket item checking. For instance, an operator may appear busy by virtue of looking at her computer screen, while in fact paying little attention to her work. In addition, there are significant physical barriers (computer monitors, desk screens...) between the workers in the rooms of our setting. These barriers make it impossible to observe the behaviour of

[23]The preferential allocation of scarce resources such as police officers to co-located incidents and in detriment of other incidents could also be regarded as an alternative channel. The evidence in Section 4 showing the lack of negative spillovers is inconsistent with this alternative channel.

[24]Note that face-to-face communication could lead to the higher motivation of its receiver (in this case, the radio operator). Storper and Venables (2004) argue persuasively that face-to-face communication can serve as a signal about the importance of a task, thereby stimulating a 'psychological rush' that leads to greater and better efforts. In our context, it is possible that discussing an incident in person may induce the operator to devote more time and effort to it, and this channel is not incompatible with the higher ability to deal with the incident resulting from a richer information set. Similarly, to the extent that the act of communicating face-to-face itself requires effort, it is by construction co-linear with it.

all but the closest co-workers, unless a handler actively stands up from her desk. While it is possible in theory for a handler to stand up and watch over the operator's shoulder in silence, we think that is an unlikely possibility.

Evidence on the Handler's Effort Mechanism The first alternative mechanism consists of the handler communicating better electronically. We now test whether there is any evidence of the handler being more precise and thorough in the electronic communication of co-located incidents. We have three good measures of this communication. The first one is the handler's creation time: the time elapsed between the handler answering the call and the creation of the incident in the GMPICS system. Remember that this creation time takes place *before* the radio operator is officially informed of the incident's existence. We expect that a more thorough and precise electronic communication will require more time devoted to writing the description of the incident, and probably also to the elicitation of the information from the caller. In Column 1 of Table 5 we however replicate our baseline specification using creation time as dependent variable, and find that it is unaffected by co-location.

As complementary measures of the quality of the electronic communication, we use the number of characters and number of words in the first line of the description of the incident[25]. Unsurprisingly, these two variables are very correlated with each other, even after conditioning on the baseline set of controls (Appendix Table A8). They are also strongly correlated with the creation time, suggesting that, despite their coarseness, there is valuable information in them. In Columns 2 and 3 of Table 5 we find that these variables are not different for co-located incidents.

To conclude, we find no evidence that the electronic information inputted by handlers is better or worse for co-located incidents, relative to other incidents. Therefore, higher effort on the handler's part does not appear to be an important mechanism in our setting.

Indirect Evidence on the Face-to-Face Communication Mechanism The mechanisms outlined above entail different predictions about the behaviour of the handler after the incident has been created, in particular with respect to the likelihood that the handler is 'not ready' to take a new call. Consider first the alternative mechanism whereby the

[25]Unfortunately, due to a combination of technical challenges and the extreme confidentiality of this information, we were not able to obtain the full content of these descriptions. The first line of the incident description consists of a maximum of 210 characters, and serves as a quick summary of the nature of the incident. When operators have more than one incident open at one time, they typically only see the first line of this description, which then plays a role similar to the subject of an email in an inbox.

operator exerts more effort for co-located incidents. Handlers are continually monitored by their supervisors, and are expected to remain at their desks unless there is a reason to leave them. Therefore, any handler exerting visual pressure on an operator would typically be doing so from her desk, an activity that is perfectly compatible with being available to take a new call. Similarly, the notion that operators are psychologically prone to exert more effort for co-located incidents does not require any change in behaviour on the handler's part. In particular, it does not require handlers being more or less willing to take new calls after creating co-located incidents.

Face-to-face communication, on the other hand, is an activity that typically requires the handler's full attention. Being in 'ready' status while talking to an operator risks having to either ignore an incoming call (an offence so serious that it is likely to trigger disciplinary action) or abruptly cut short the discussion of important details. Therefore, a prediction of the face-to-face communication channel is that, following the creation of co-located incidents, handlers will be more likely to be in 'not ready' status. This prediction is not shared by alternative plausible channels.

In Column 4 of Table 5 we replicate the baseline specification using the length of the 'Not Ready' interval following an incident as the dependent variable. The *SameRoom* coefficient is 2.5% and statistically significant, suggesting that handlers step away from their desks (or remain on their desks while being unavailable) for longer periods following co-located incidents. In Column 5 of Table 5, we repeat this exercise using as dependent variable a dummy for whether the handler signals her immediate availability to take new calls or instead takes some 'not ready' time at all. Again, we find that the likelihood of not being immediately available is higher for co-located incidents. While there is no conclusive evidence that they are using this time to communicate in person with the operator, we interpret this finding as strongly suggestive of face-to-face communication being the main mechanism through which co-location improves performance.

6 Heterogeneity

In this section we identify characteristics of incidents, teammates and the working environment that are associated with a higher effect of proximity on performance. We do this for two reasons. Firstly, the exercise is valuable from a policy perspective. A better understanding of the specific circumstances in which co-location has the highest impact can help guide the decisions of organisations searching for the optimal geographical configuration of its personnel and activities. Secondly, studying the heterogeneity of the effect can provide additional evidence consistent with the face-to-face communication mechanism.

Characteristics of Incidents We first examine whether the effects from Table 2 are stronger for some types of incidents, relative to others. We focus on two particularly relevant characteristics of incidents: their urgency and the complexity of the information required to understand and describe them. The main hypothesis is that if co-location improves performance because it enables face-to-face communication, we should find a stronger effect for complex incidents where a lot of information must be transmitted. In addition to being intuitive, this hypothesis is consistent with the vast literature arguing that human production is at a lower risk of being substituted by technology for (cognitive) non-routine tasks, relative to routine tasks (Acemoglu and Autor, 2011).

We also study empirically the relation between the urgency of an incident and the effect of co-location on performance. In principle, it is unclear what the sign of this relation should be. On the one hand, the ability to communicate information quickly might be more valuable and therefore used more often when an allocation decision needs to be done faster. On the other hand, in very urgent incidents (e.g. a serious crime in progress) the operator may not want to wait for many nuanced details and will instead allocate an officer as quickly as possible. If that is the case, more urgent incidents will be associated with a lower effect of co-location on allocation time.

Both theoretical concepts, 'urgency' and 'information intensity', have elusive empirical counterparts. The information intensity of incidents is difficult to measure because we unfortunately lack access to complete characterisations of the features of every incident in our dataset. We also lack the full GMIPCS descriptions recorded by handlers, although of course any classification of an incident reliant on the actions taken by its call handler would risk confusing the diligence or ability of the handler with the intrinsic features of the incident.

To overcome the measurement challenges above we use information based on generic incident types to create an indirect measure of information intensity, as follows. We first classify each incident according to its opening code/grade combination. We then regress creation time (the time elapsed between the handler answering the call and the creation of the incident) on every one of the resulting 144 dummies. The fitted values from this regression, which constitute our measure of (predicted) information intensity, capture how long on average it takes for handlers to extract information from the caller and record it in GMPICS, for every incident type. Although the measure is undoubtedly coarse, our interpretation is that incident types with high average creation time should be those where the amount and complexity of information is typically the largest. We construct our measure of (predicted) urgency in an equivalent way, this time regressing allocation time on the 144 incident type dummies (naturally, lower average allocation time is interpreted as higher urgency).

We interact our measures of information intensity and urgency with the same room dummy in the baseline regression. For ease of interpretation, these measures are entered as above-median dummies. The estimates are displayed in Table 6. We find first that incident types of high average information intensity are associated with a higher effect of co-location on performance[26]. We also find weaker evidence on the urgency of incidents exacerbating the effect of co-location. In particular, the estimate for the interaction with urgency is negative, although statistically significant only in the allocation time regression[27].

We interpret the estimates from Table 6 as indicating that co-location does not increase performance for non-urgent, non-complex incidents. It, however, decreases allocation time (respectively, response time) by 4% (respectively, 2.7%) for incidents that are above-median both in their urgency and their information intensity. The estimate on the interaction with information intensity is, in particular, consistent with the notion that co-location enables an additional communication channel, leading to higher performance for incidents when a lot of communication is necessary.

Characteristics of the Working Environment In our second heterogeneity exercise, we study whether co-location improves performance more when workers have to deal with more incidents. Our main interest is in the workload of the operator, because it is for operators that a high number of incoming incidents in their subdivision can start to accumulate, exerting competing demands on their attention. Our hypothesis is that, if co-location allows operators to quickly resolve any doubt through face-to-face communication, it should be

[26] This finding is robust to measuring information intensity with quintiles (Appendix Figure A2) and in parametric (log) format (Appendix Table A4). It is also robust to building the information intensity prediction exclusively with out-of-sample (i.e. pre-November 2009 and post-January 2012) observations (Appendix Table A3).

[27] Both effects become statistically stronger if information intensity is measured parametrically (Appendix Table A4). However, we find that the effect of co-location does not vary when we use a simpler and coarser measure of the urgency of an incident: its grade. Although the effect is stronger for Grade 1 incidents, relative to Grade 2 and Grade 3, the differences are not statistically significant (see Appendix Table A9).

more valuable when the time and effort of the operator are scarce, that is, in periods of higher workload[28].

Our measure of the operator's workload is the number of incidents created in the subdivision that the operator is overseeing during the hour of the index incident (note that there is a single operator responsible, at any one time, for a subdivision). For ease of interpretation, we enter this measure in the baseline regression as an above-median dummy, both by itself and interacted with the same room variable.

The results are displayed in Table 7. We first find that allocation and response times are slower when the operator is busier, as expected. Our main interest is in the estimate of the interaction between the same room variable and the high operator workload dummy, which we find to be negative and statistically significant. The estimated coefficients indicate that co-location reduces allocation time (respectively, response time) by 1.1% (respectively, .8%) during periods of low operator workload, but 2.9% (respectively, 2%) during periods of high workload. This finding lends support to our hypothesis that the benefit of communicating personally with the handler is higher when the operator is more pressured for time and needs to gather information more quickly[29].

Characteristics of the Workers We now examine whether the effect of co-location on performance is stronger when the teammates share the same age and gender, and have worked together more often in the past. We expect this to be the case, for two reasons. Firstly, workers of a similar background (or more familiar with each other) may feel more likely to initiate the face-to-face communication exchanges that transmit information regarding an incident. This is because they may be more likely to sit close to each other, or, conditional on the within-room distance, they may be more likely to leave their desk and talk to each other. Secondly, in person communication may also be more efficient among these types of

[28]By contrast, our understanding of the institutional environment is that the notion of being 'pressured for time' is less meaningful for handlers. Handlers deal with incidents sequentially and share the responsibility of responding to incoming calls with a large number of colleagues (since every handler can handle incidents from every Manchester area). Together with the fact that handlers are not responsible for the allocation of officers to incidents, this implies that we do not have a strong hypothesis about the relation between our measure below of handler workload and the effect of co-location on performance

[29]Our measure of the handler workload is very coarse, mostly because as discussed earlier, the notion that handlers are busier in some periods relative to others is not clear-cut. We use the (above-median dummy of the) number of incoming calls during the index hour, divided by the number of available handlers. Because this variable is defined at the Manchester-wide level, it is absorbed in the baseline regression by the hour fixed effect. We find in Table 7 that the coefficient on the interaction with the same room variable is smaller in magnitude and only weakly statistically significant.

workers[30].

In Table 8 we display estimates of our baseline specification, where we add a same gender dummy, the (log of the) difference in age, and the (log of the) number of past incidents in which handler and operator worked together. We further interact these variables with the same room variable. To isolate the effect of the handler/operator *pair* experience, the specification controls for the individual experiences of handler and operator and their interactions with the same room variable.

Our main finding is that the estimates for the three interactions of interest are statistically significant and of the expected sign. For instance, the effect of co-location is 2.9% when handler and operator share the same gender, but only 1.3% when they do not. A 10% increase in the age difference (respectively, number of past interactions) between handler and operator decreases the effect of co-location on performance by 2.6% (respectively, it increases it by 2.2%). These findings are consistent with the notion that face-to-face communication, and therefore co-location, leads to higher performance among co-workers that know and understand each other better[31]. On the other hand, the non-significant interactions with individual experience suggest that, unless it is specific to the teammate in this particular incident, individual experience does not by itself allow workers to exploit better the potential advantages of co-location.

7 The Cost of Face-To-Face Communication

Section 5 has shown that handlers spend 2.5% more time unavailable to take new calls following the creation of co-located incidents. This unavailability imposes a cost on the organisation, as it contributes to incoming calls being answered with a longer delay. In this

[30] Storper and Venables (2004) discuss how the transmission of uncodifiable information (at which face-to-face communication excels) depends on a 'communication infrastructure' that is specific to a sender-receiver pair. This infrastructure is likely improved through learning by doing, leading to more efficient face-to-face communication as the teammates accumulate experience with each other. It is also likely more efficient among demographically proximate teammates. Alternatively, we could interpret demographic proximity as a proxy for the existence of friendship ties between two co-workers (Bandiera, Barankay and Rasul, 2010). If workers are more willing to and effective at communicating face-to-face with their friends, a similar prediction for the relation between demographic proximity and the effect of co-location on performance would arise.

[31] We find qualitatively similar results when age and past interactions are measured as above-median dummies (see Appendix Table A5). While not the focus of this paper it is interesting to note that, even when teammates are not co-located, a similar age and a longer experience with each other are still associated with higher performance (although this is not the case for the same gender variable). A potential explanation of these estimates is that, given the complexity of the information that must often be transmitted, even electronic communication is more efficient among these types of teammates.

section we provide a framework to measure the opportunity cost of the time spent in face-to-face communication, so that it can be compared to its benefit. We then compute this cost in our organisation.

Theoretical Framework We formalise the process by which calls to the police arise, join the call queue and are answered. Assume a population of individuals (of normalised size 1) who can potentially call the police. Every individual can be in one out of three states: dormant (waiting for an incident to happen), in the call queue, or on the phone with the handler. x_i, $i = 1, 2, 3$ denotes the share of individuals in each state. $H < 1$ handlers are on duty to answer calls.

Transitions between states are as follows. Dormant callers join the queue at an exogenous rate a per unit of time. All callers must spend at least one unit of time there before being assigned a handler. When a call is being answered, it terminates (and the caller re-joins the dormant pool) at a constant rate υ (with $1/\upsilon$ being the average duration of calls). The number of handlers that become available to take new calls per unit of time is υx_3. The total number of calls answered per unit of time is then $min\{\upsilon x_3, x_2\}$, since it is limited both by the number of newly available handlers and by the size of the call queue.

Using this simple framework we can show that the size of the call queue evolves over time depending on the difference between the inflow (the number of dormant individuals who encounter an incident) and the outflow (the number of queued calls answered by handlers):

$$\frac{\Delta x_2}{\Delta t} = a\,(1 - x_2 - x_3) - min\{\upsilon x_3, x_2\} \tag{3}$$

Similarly,

$$\frac{\Delta x_3}{\Delta t} = min\{\upsilon x_3, x_2\} - \upsilon x_3 \tag{4}$$

If $\upsilon x_3 < x_2$, then it must be that all handlers are busy and $x_3 = H$. Combining equations (3) and (4) and assuming steady state, we compute the time in the queue for incoming calls, q^*, as:

$$q^* = \begin{cases} \frac{(1-H)}{\upsilon H} - \frac{1}{a} & \text{if} \quad H < \frac{a}{a+\upsilon+a\upsilon} \\ 1 & \text{if} \quad H \geq \frac{a}{a+\upsilon+a\upsilon} \end{cases} \tag{5}$$

This framework generates the following predictions. First, incoming calls are answered immediately when there are many handlers (H high), few dormant calls become actual calls (a low) and calls are brief (υ high). Secondly, $\frac{\partial q^*}{\partial(1/\upsilon)} > 0$ so an increase in average call length leads to longer queuing times. Lastly, this effect is lower when the number of handlers is higher, $\frac{\partial^2 q^*}{\partial(1/v)\partial H} < 0$. We can interpret an increase in H as the increase in organisational slack, as the same amount of incoming work is divided over a higher number of workers. Therefore, this model predicts that an increase in slack both decreases queuing times and reduces the effect of higher average call duration.

Computing the Opportunity Cost of Face-To-Face Communication Section 5 provided evidence of an increase in 'not ready' time following the creation of co-located incidents. This is equivalent in our framework to an increase in the duration of the call, as it mechanically prevents handlers from relieving the pressure in the call queue. We now use information on *all* calls (not just the ones that led to the creation of incidents) to relate call duration, the number of calls and the number of on-duty handlers to the average time spent in the call queue. The resulting coefficients allow us to understand the *opportunity cost* of an additional second spent dealing with a previous call. We estimate:

$$q_i = \alpha_i + \gamma n_i(\tau) + \delta h_i(\tau) + \beta d_i(\tau) + \epsilon_i \tag{6}$$

where q_i is the (log of the) queuing time of incoming call i, n_i and h_i are the (log of) number of calls and on-duty handlers in a time window before i, and d_i is the (log of) average duration of answered calls in the same time window.

Table 9 Panel A shows that the estimated elasticity of average call duration on queuing time ranges from .40 to .46. We can compute the effect that an increase in the duration of a single call j has on the queuing time of future calls as follows. First, note that such an increase has an effect on the queuing time of *a single future call* i that can be computed as $\hat{\beta}\frac{exp(q_i)}{TD_i}$, where $exp(q_i)$ is the queuing time of i and TD_i is the total duration of the calls preceding i (which include j). Aggregating over the K calls that follow j, we can write the overall effect of an increase in j's duration as $\hat{\beta}\sum_{i=j+1}^{j+K}\frac{exp(q_i)}{TD_i}$.

The statistic $\hat{\beta}\sum_{i=j+1}^{j+K}\frac{exp(q_i)}{TD_i}$ can be interpreted as the opportunity cost (in terms of additional queuing time of future calls) of increasing the duration of call j by one second. This statistic can be computed directly from our dataset, using the elasticity estimated in Table 9 and information on the queuing time of every call, together with the duration of the calls preceding it. Using a time window of 60 minutes, we calculate it as 1.16 seconds. In Table 5 we estimated that co-located incidents increase 'not ready' time by 2.5%. Evaluated at the mean of 'not ready' time (66 seconds), co-located incidents are therefore associated with a cost of $1.16 \times 2.5\% \times 66 = 1.9$ seconds. In our organisation, this is arguably a small cost, when compared with the decreases in allocation and response times of 76 and 104 seconds respectively that we estimated in Section 4[32].

Motivated by our theoretical framework, we expect the opportunity cost of face-to-face communication to be lower when organisational slack, as captured by the relation between on duty handlers and incoming calls, is higher. In Panels B and C we repeat the exercise in Panel A for the subsamples of calls with high and low organizational slack. Consistently with the prediction that increasing a call's duration is less costly when the relative number of handlers is higher, we find a higher elasticity in Panel C (high slack) and a lower in Panel B (low slack). Replicating the analysis above, we calculate costs associated with co-location of 3.2 (respectively 1.1) seconds, for periods of low (respectively high) slack.

Overall, our analysis highlights the importance of measuring the opportunity cost of the time engaged in face-to-face communication, as well as the dependence of this cost on the slack characterising the organisation. In our setting, we find this cost to be much lower than the benefit.

8 Conclusion

This paper has provided evidence of a causal relation between proximity and performance, in a teamwork setting characterised by the communication of complex information. A series of additional tests point towards face-to-face communication as the most important mechanism. We have also provided additional evidence on the heterogeneity of the main result and highlighted that face-to-face communication has opportunity costs, as well as benefits. We are not aware of any existing study studying these questions that is comparable in terms of the detail of analysis and the credibility of the estimated effects.

One immediate policy prescription for the specific organisation that we study is in terms of supervisors' awareness of the benefits of communication between co-workers. Discussions between handler and operator following the creation of incidents were not encouraged and were even frowned upon by some supervisors. Because the cost of communication is orders of magnitude smaller than the benefit, one implication is that, in our specific context, there may be too little communication among co-located workers rather than too much. This

[32]The benefits and costs associated with co-location affect different types of calls. The costs are for the average call, including those which do not lead to incidents and those leading to incidents that are not deemed to merit a response within four hours of the incident creation. The benefits are instead concentrated on the calls that are deemed important enough to be assigned to a radio operator.

indicates that a change of norms and culture to encourage more communication could be potentially enhancing. More generally, however, the fact that the cost of communication is not zero indicates that the limitations on the information sets of decision-makers highlighted by Hayek (1945) and Arrow (1974) are unlikely to be fully overcome.

Our findings provide direct guidance to managers organising the geographical distribution of activities. Most directly, the evidence casts doubt on the appropriateness of telecommuting policies in settings where workers must communicate complex information to each other. Our results further suggest that telecommuting may be particularly unsuitable (and co-location of teammates particularly valuable) when activities are informationally demanding, workers are homogenous and likely to be busy, and teams are likely to be stable.

There may be additional implications for recruitment policy. A large literature in organisational behaviour is concerned with the advantages and challenges of diversity in the workplace (Shore et al., 2009). In economics, a parallel body of work has studied the differences in productivity between homogeneous and heterogeneous teams (Hamilton et al. 2012, Hjort 2014, Lyons 2016), a question of clear recruitment policy implications. Our results indicate that the relative benefits of homogeneity depend on the geographical configuration of activities. In particular, a more homogeneous organisation is most valuable when workers are likely to be based in the same physical space.

Our results also identify a distinct driver of firm-specific human capital accumulation (Topel, 1991), with implications for staff turnover and team-rotation policies. Consistently with Hayes et al. (2006) and Jaravel et al. (2016), we find in Section 6 that workers accumulate human capital that is specific to a particular co-worker. Importantly, our finding is however that this capital is most valuable (or more rapidly accumulated) among co-located workers. It follows that managers should be wary of the team disruption induced by turnover particularly when the team members work in close proximity.

FIGURES

Figure 1
Operational Communications Branch

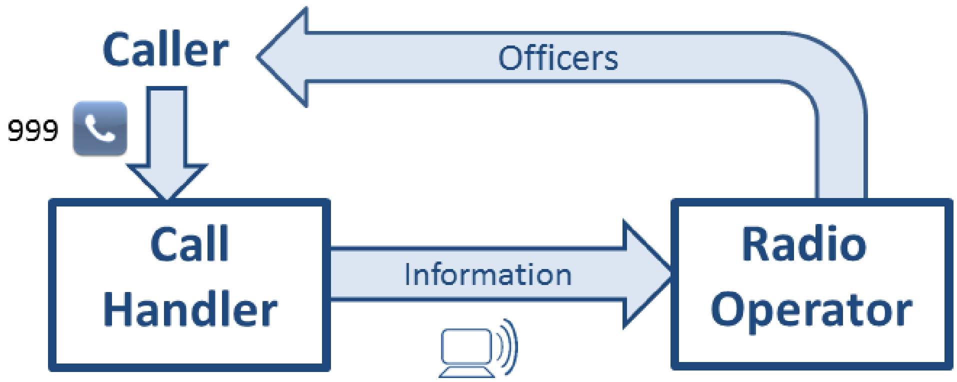


Figure 2
Location and Radio Operations Coverage of OCB Rooms

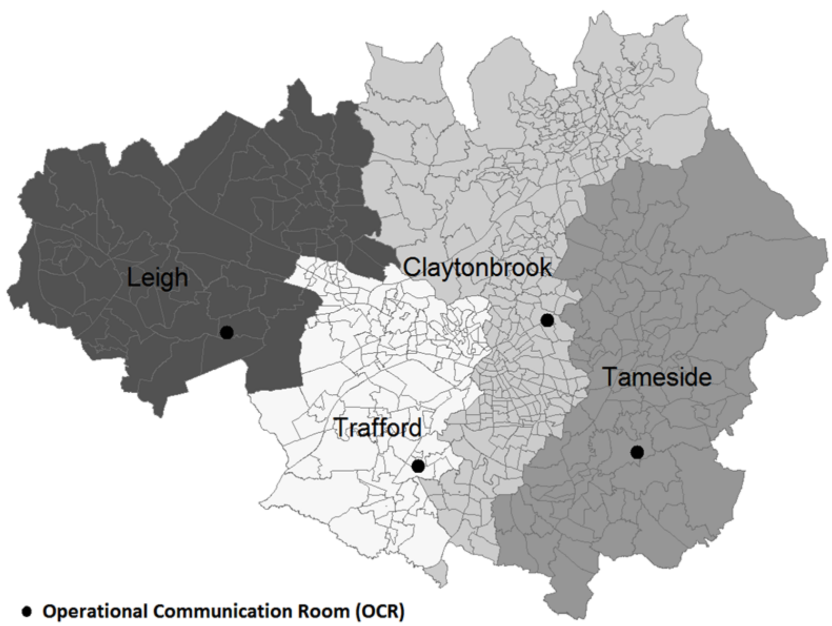


Figure 3A: Same Room = 1

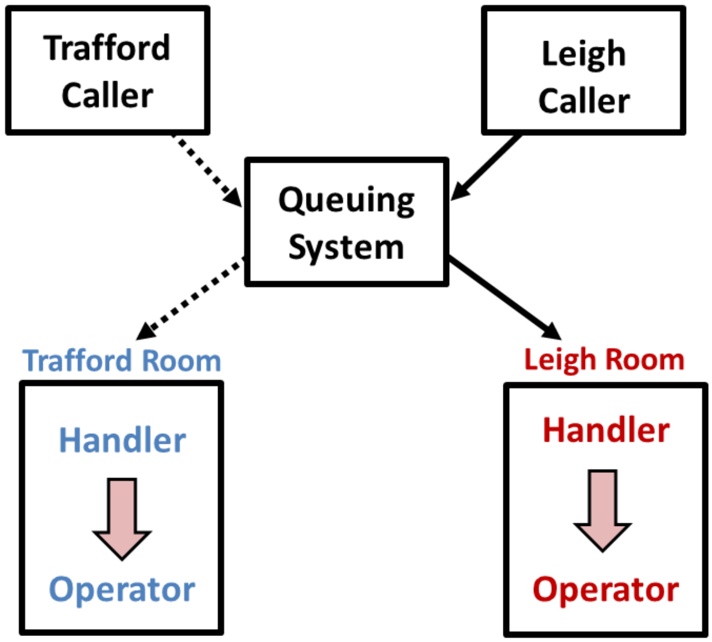


Figure 3B: Same Room = 0

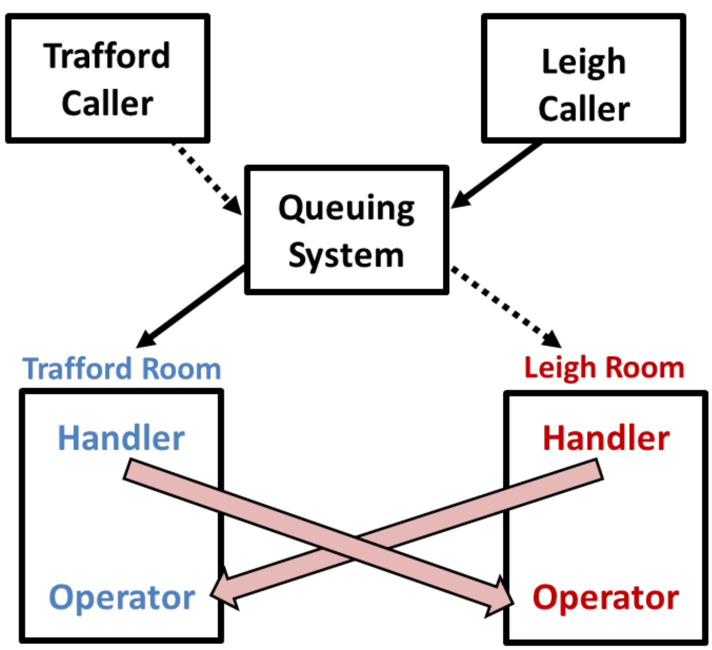
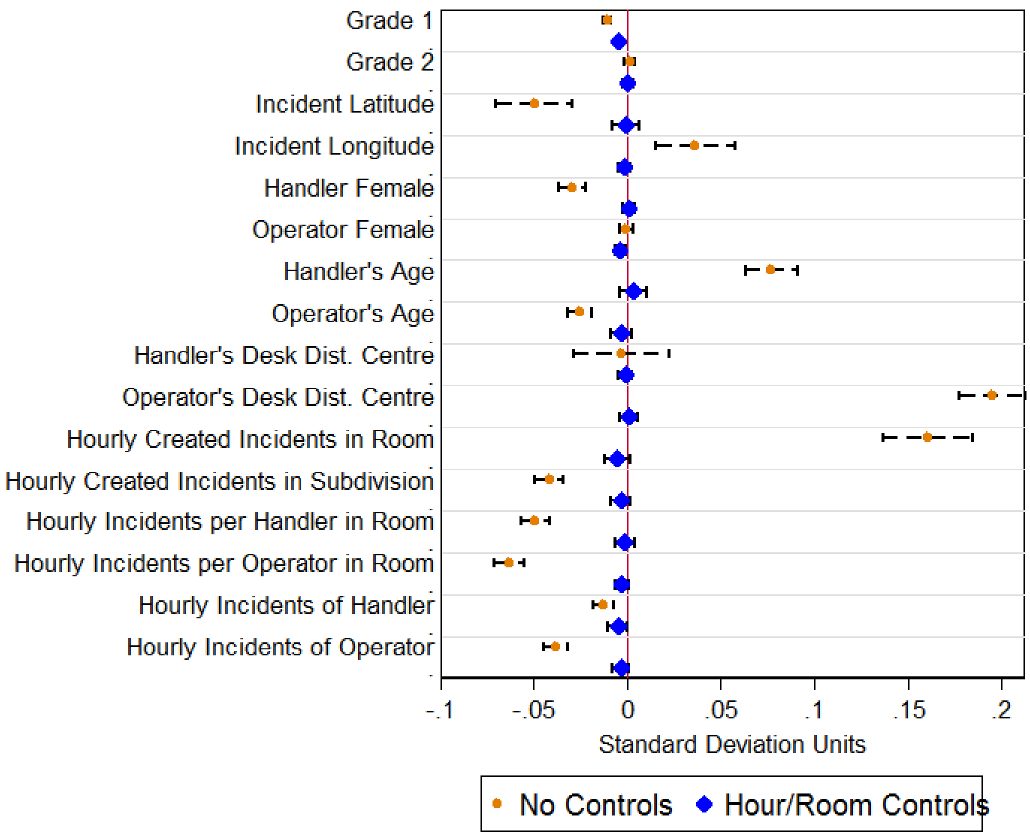


FIGURE 4: Balance of Incident, Worker and Room Characteristics on Same Room



Each row in the figure displays the results of two regressions, where the row variable is the dependent variable and Same Room is the independent variable. The first regression includes no controls and the second regression controls for Year X Month X Day X Hour of Day, Radio Operator Room and Call Handler Room. The displayed 95% confidence intervals are for the coefficient of the Same Room variable. Non-binary dependent variables are standardised. Standard errors are clustered at the Year X Month X Radio Operator Room level. Grade 1, Grade 2, Handler Female and Operator Female are the only dummy variables. Handler's Desk Dist. Centre is the euclidean distance between the handler's desk and the centre of the room. Hourly Incidents per Handler in Room is the number of incidents created during the hour of the index incident, divided by the number of handlers working during that hour. A similar definition applies to Hourly Incidents per Operator in Room. Hourly Incidents of Handler is the number of incidents created by the handler in charge of the index incident, during the hour of creation. Hourly Incidents of Operator is the number of incidents allocated by the operator in charge of the index incident, during the hour of the creation of the incident.

Figure 5: Example of OCB Room Floorplan

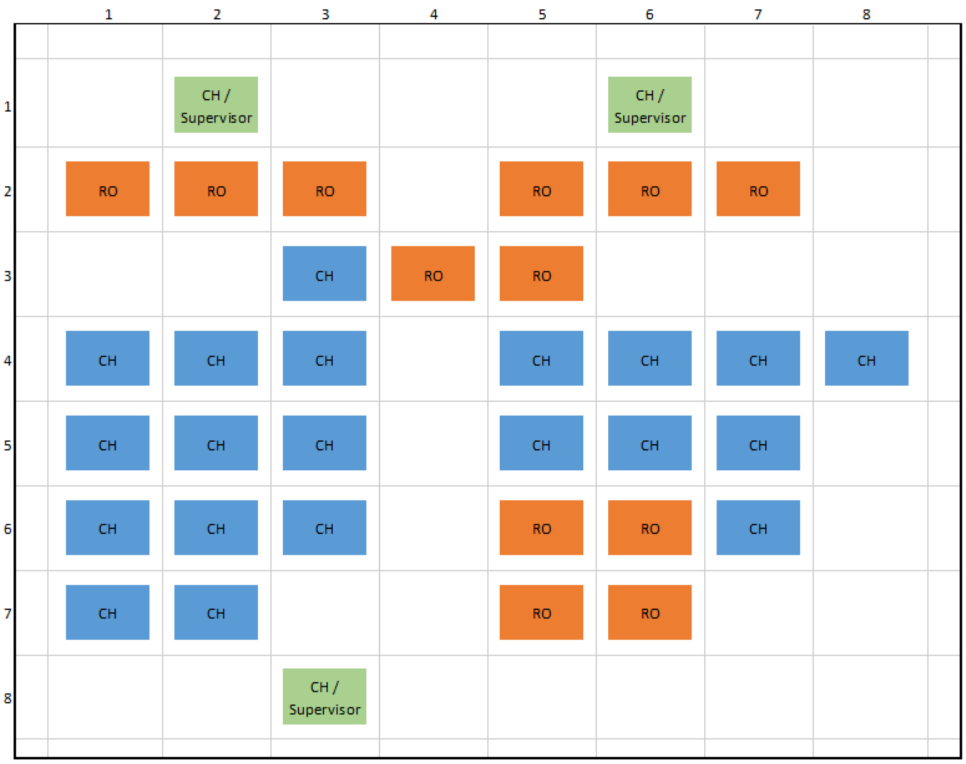
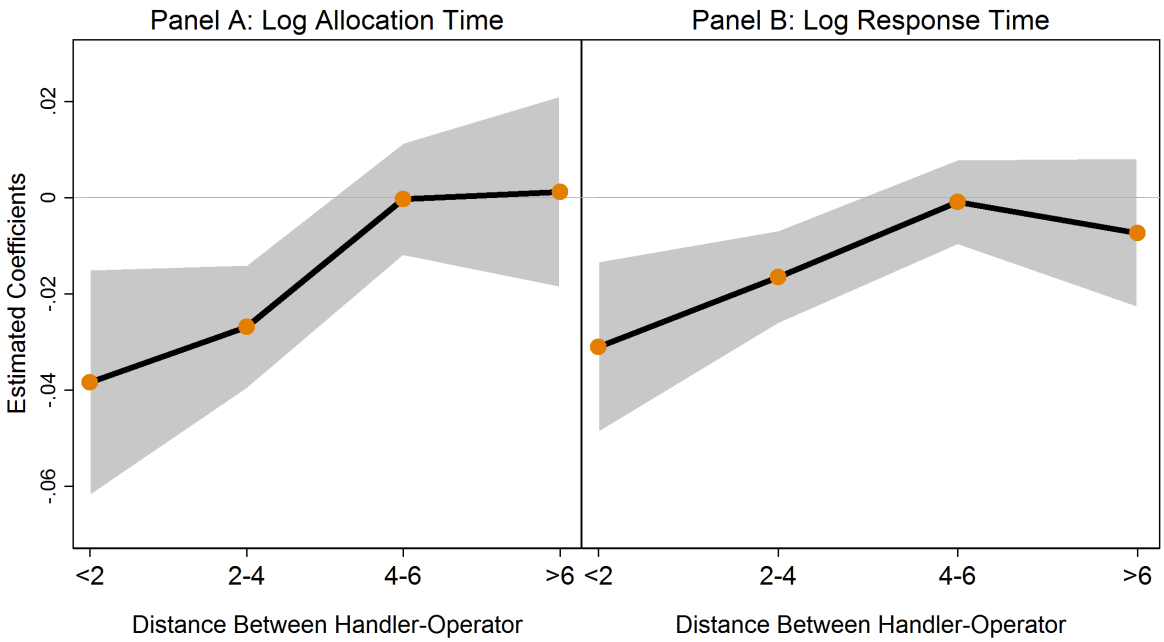
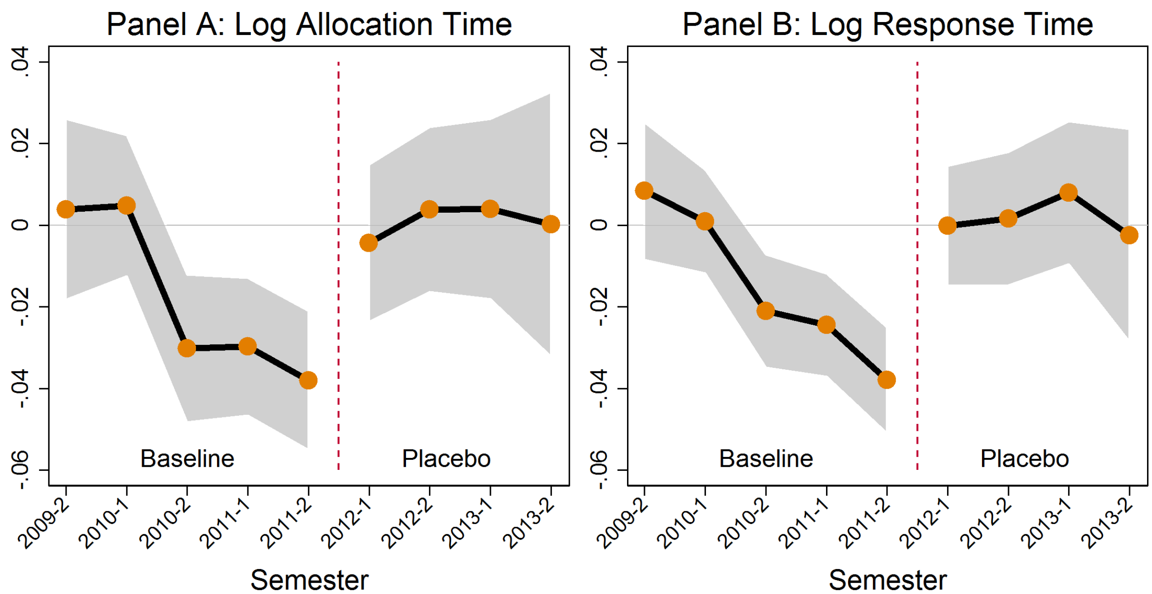


Figure 6: Heterogeneity of the Effect of Same Room By Distance Inside Room



Each panel displays a different regression. The displayed coefficients are for Same Room X Distance Handler/Radio Operator. Distance is the euclidean distance between the desks. 95% confidence intervals are displayed in the shaded grey area. All regressions control for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room X Year, Call Handler Room X Year, Radio Operator and Call Handler. Standard error are clustered at the Year X Month X Radio Operator Room level.

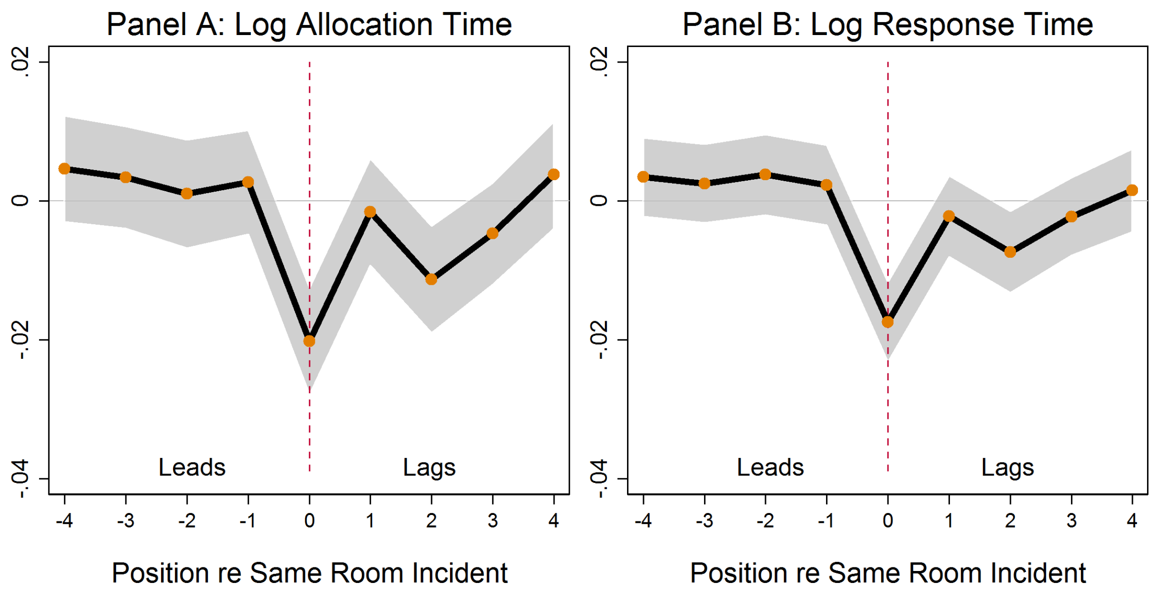
Figure 7: Heterogeneity of the Effect of Same Room By Semester, Including Placebo Period



Each panel displays two different regressions. The displayed coeffcients are for the interaction of Same Room (or Placebo Same Room) with the semester indicators. The samples on the left side of each panel are the baseline samples. The samples on the right side of each panel include observations from 2012/13, when all the Call Handlers were based in Trafford, and all the Radio Operators were based in Claytonbrook and Tameside. We regard the 2012/13 period as the placebo period. For this period, the Placebo Same Room variable is based on the Radio Operator and Call Handler locations during the second semester of 2011. All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level.

Figure 8: Investigating Spillovers
from Same Room Incidents to Other Incidents

Leads and Lags Around the Same Room Incident



Each panel displays a different regression. The displayed coefficients are for Same Room (position = 0) and four leads and four lags. The leads are the four incidents prior to the Same Room incident assigned to the Radio Operator. The lags are the four incidents following the Same Room incident. All regressions control for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room X Year, Call Handler Room X Year, Radio Operator Identifier and Call Handler Identifier. Standard error are clustered at the Year X Month X Radio Operator Room level.

TABLES

TABLE 1: SUMMARY STATISTICS

	Mean	Median	SD	Min	Max
Allocation Time (min.)	64.124	4.583	276.568	0	21331.78
On Target Allocation	.748	1	.434	0	1
Response Time (min.)	87.484	19.933	311.166	.05	21391.92
On Target Response	.877	1	.328	0	1
Creation Time (min.)	3.889	2.85	4.946	0	219.533
Grade 1	.197	0	.398	0	1
Grade 2	.432	0	.495	0	1
Same Room	.229	0	.42	0	1
Distance inside Room	4.34	4.243	1.782	.5	11.885
Handler Female	.27	0	.444	0	1
Operator Female	.498	0	.5	0	1
Handler's Age	38.406	38	11.471	19	64
Operator's Age	45.15	46	8.243	19	66

This Table reports summary statistics for the baseline sample (N=957137). An observation is an incident. Allocation time is the time between the creation of the incident by the call handler and the allocation of a police officer by the radio operator. Response time is the time between creation of the incident and the police officer arriving at the scene. On target allocation (respectively, response) is a dummy taking value one if the allocation time falls wihin the UK Home Office targets, which are 2, 20 and 120 minutes (respectively 15, 60 and 240 minutes) for Grades 1, 2 and 3. Creation Time is the time between the handler answering the call and the creation of the incident in GMPICS. Grade 1 and Grade 2 are dummies for the grade of the incident. Same Room is a dummy when handler and operator are located in the same room. Distance inside the room is the euclidean distance between the handler and the radio operator desks. This variable is defined in this table only when same room is equal to one (N=219184). Handler female and operator female are dummy variables.

TABLE 2: BASELINE ESTIMATES

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Dep. Variable	**Log Alloc. Time**	**Log Response Time**	**On Target Alloc.**	**On Target Response**	**Cleared**
Same Room	-.02***	-.017***	.004***	.002***	-.001
	(.004)	(.003)	(.001)	(.001)	(.003)

This table displays estimates of OLS regressions of five different performance measures on whether the call handler and the radio operator are located in the same room. The sample includes all incidents received by the GMP between November 2009 and December 2011 (N=957137). In Column (1) the performance variable is the log of the allocation time (i.e. the time between the creation of the incident by the call handler and the allocation of a police officer by the radio operator). In Column (2) the performance variable is the log of the response time (i.e. the time between the creation of the incident and the police officer arriving at the scene). In Columns (3) and (4) the dependent variables are dummy variables taking value one if allocation and response times fall within the UK Home Office targets, respectively. The target response times for Grades 1, 2 and 3 are 15, 60 and 240 minutes, respectively. The target allocation times are 2, 20 and 120 minutes. In Column (5) the dependent variable is a dummy taking value one if the crime was cleared. In Column (5) the sample includes only incidents that the police classified as crimes (N=156550). All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE 3: HETEROGENEITY OF SAME ROOM BY DISTANCE INSIDE ROOM

	Individual F.E.		Pair F.E.	
Dep. Variable	**(1) Log Alloc. Time**	**(2) Log Response Time**	**(3) Log Alloc. Time**	**(4) Log Response Time**
Same Room	-.049***	-.035***	-	-
	(.012)	(.01)	-	-
Same Room X Log Distance	.026***	.018***	.027***	.017**
	(.009)	(.007)	(.01)	(.008)

This table displays estimates of OLS regressions of allocation time and response time on whether the call handler and the radio operator are located in the same room, interacted with the distance between their desks when they are in the same room. The sample includes all incidents received by the GMP between 2009 and 2012 (N=957137). The distance between their desks is calculated as the euclidean distance in the floorplans provided by the GMP. All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room X Year and Call Handler Room X Year. Columns (1) and (2) also include Radio Operator and Call Handler Identifiers. Columns (3) and (4) include Radio Operator/Call Handler Pair Identifiers. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE 4: INVESTIGATING SPILLOVERS TO OTHER INCIDENTS, BY SAME ROOM INCIDENTS

	Spillovers by Same Room Incidents during Period:					
	60 min.		30 min.		15 min.	
Dependent Variable	**(1) LogAlloc Time**	**(2) LogResp Time**	**(3) LogAlloc Time**	**(4) LogResp Time**	**(5) LogAlloc Time**	**(6) LogResp Time**
% Same Room Incidents Received by Operator	.005	.004	.006	.007	.009	.007
	(.005)	(.004)	(.006)	(.004)	(.007)	(.005)

This table investigates potential spillovers from Same Room incidents into other contemporaneous incidents. The dependent variables in the OLS regressions are log of allocation time and log of response time. The independent variable is the percentage of incidents during the index incident time period for which the call handler and the radio operator were located in the same room, excluding the index incident. In Columns (1) and (2) the period comprises of 60 minutes (respectively, 30 minutes for columns (3) and (4) and 15 minutes for columns (5) and (6)). All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. The regressions also include indicators for whether there were no calls received by the Radio Operator during the time period. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE 5: INVESTIGATING EFFECTS ON OTHER ACTIONS BY THE HANDLER

Dep.Var.	(1) Log Creation Time	(2) Log Number of Characters	(3) Log Number of Words	(4) Log Not Ready	(5) Not Ready>0
Same Room	.00446	-.0004	-.00028	.0252***	.00447**
	(.00326)	(.00138)	(.0015)	(.00927)	(.00201)

This table displays estimates of OLS regressions of three actions by the handler prior to creating the incident, on whether the call handler and the radio operator are located in the same room. The sample includes all incidents received by the GMP between November 2009 and December 2011. In Column (1) the dependent variable is the log of the creation time (i.e. the time between the handler answering the call and the creation of the incident). In Column (2) the dependent variable is the number of characters in the first line of the description of the incident (maximum number of characters = 210). In Column (3) the dependent variable is the number of words in the first line of the description of the incident. In Column (4) the dependent variable is the log of the not ready time following the creation of the incident. In Column (5) the dependent variable is a dummy for whether the not ready time takes value bigger than zero. All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE 6: HETEROGENEITY OF SAME ROOM BY INCIDENT CHARACTERISTICS

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Same Room	.001	-.001
	(.008)	(.006)
Same Room X Urgent	-.019***	-.007
	(.008)	(.006)
Same Room X Information Intensive	-.021***	-.02***
	(.008)	(.006)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted in measures of the urgency and information intensity of an incident. To compute the information intensity variable we use the sample from 2008 to 2014 and regress the creation time (i.e. the time between the handler answering the call and the creation of the incident) on the opening code/grade indicators. We then assign to every opening code/grade incident type its predicted creation time, and label an incident type as being information intensive if its predicted creation time is above the median. To compute the urgency variable, we do a similar exercise using allocation time instead of creation time. All regressions also include indicators for Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler, and opening code/grade indicators. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE 7: HETEROGENEITY OF SAME ROOM BY WORKER WORKLOAD

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Same Room	-.011*	-.008*
	(.006)	(.004)
Same Room X High Operator Workload	-.018**	-.012*
	(.008)	(.006)
Same Room X High Handler Workload	-.006	-.01*
	(.008)	(.006)
High Operator Workload	.128***	.046***
	(.005)	(.004)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted with measures of the workload of the operator and handler. To compute the operator workload measure, we use the number of incidents created in the operator's subdivion during the index hour. To compute the handler workload measure, we use the number of Manchester-wide incidents during the index hour, divided by the number of handlers on duty during that hour. The variables in the regression are dummies taking value one when the workload is above the sample median. We report the uninteracted operator workload measure. The uninteracted handler workload measure is absorbed by the Year X Month X Day X Hour of Day fixed effects. All regressions also include indicators for Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE 8: HETEROGENEITY OF SAME ROOM BY HANDLER-OPERATOR DEMOGRAPHIC DISTANCE BY NUMBER OF PAST INTERACTIONS

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Same Room	-.021	-.031*
	(.023)	(.018)
Same Room X **Same Gender**	-.016**	-.019***
	(.008)	(.006)
Same Room X **Log Difference in Age**	.025***	.024***
	(.005)	(.004)
Same Room X **Log Number Past Interactions**	-.021***	-.019***
	(.005)	(.004)
Same Room X Log Handler Experience	-.004	-.003
	(.004)	(.003)
Same Room X Log Operator Experience	.005	.009*
	(.006)	(.005)
Same Gender	-.002	-.003
	(.004)	(.003)
Log Difference in Age	.013***	.01***
	(.003)	(.002)
Log Number Past Interactions	-.073***	-.061***
	(.005)	(.004)
Log Handler Experience	.058***	.045***
	(.009)	(.007)
Log Operator Experience	-.057	-.026
	(.049)	(.036)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted with whether the Radio Operator and the Handler are of the same gender, with the log of their difference in age, and with the number of previous incidents in which they have worked together. All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room X Year, Call Handler Room X Year, Radio Operator and Handler. All regressions also control for Handler Experience and Operator Experience and their interactions with Same Room. Standard errors are clustered at the Year X Month X Radio Operator Room level.

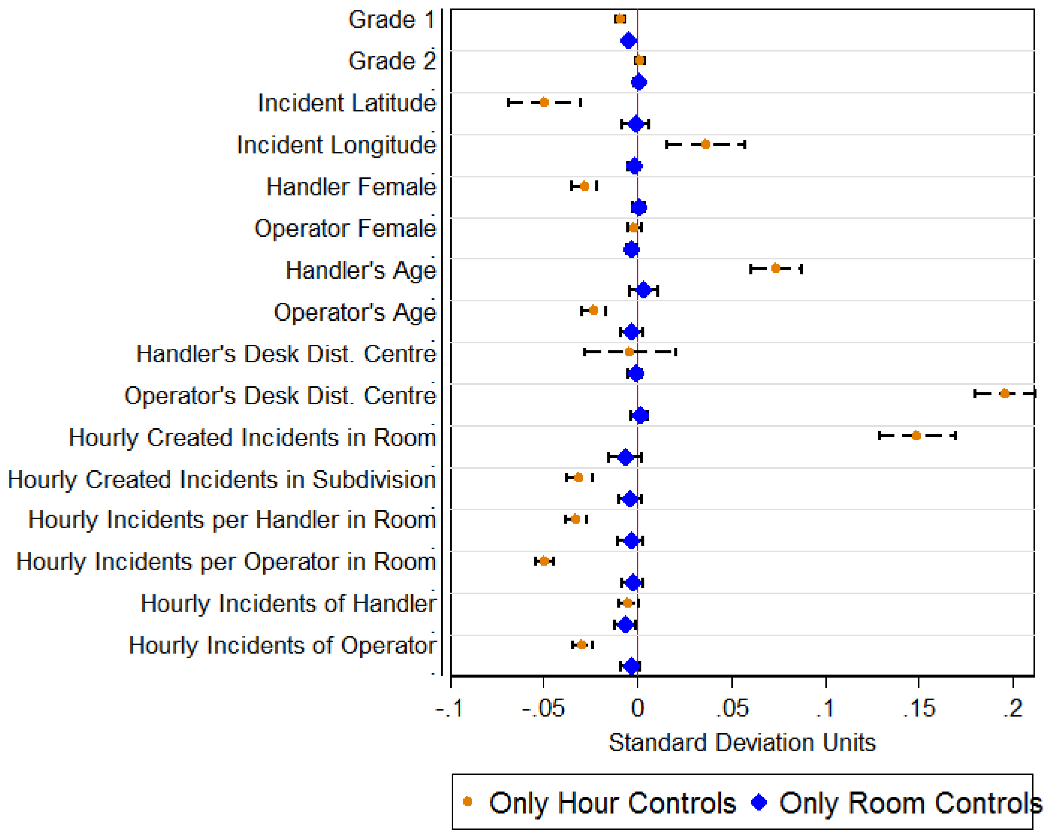
TABLE 9: OPPORTUNITY COST OF HIGHER CALL DURATION

Dep. Var. = Log Queuing Time	(1) 15 min. Window	(2) 30 min. Window	(3) 60 min. Window
Panel A: All			
Log Calls	.579***	.583***	.557***
	(.003)	(.004)	(.004)
Log Handlers	-.513***	-.514***	-.488***
	(.004)	(.004)	(.004)
Log Avg Call Duration	.46***	.457***	.4***
	(.005)	(.005)	(.006)
Panel B: High Organisational Slack			
Log Calls	.445***	.464***	.399***
	(.005)	(.006)	(.006)
Log Handlers	-.422***	-.435***	-.353***
	(.006)	(.007)	(.007)
Log Avg Call Duration	.349***	.362***	.342***
	(.005)	(.006)	(.007)
Panel C: Low Organisational Slack			
Log Calls	.846***	.766***	.611***
	(.007)	(.008)	(.008)
Log Handlers	-.625***	-.568***	-.451***
	(.007)	(.008)	(.008)
Log Avg Call Duration	.642***	.605***	.472***
	(.008)	(.009)	(.011)

This table displays estimates of OLS regressions of queuing time on measures of organisational slack and average call duration in the period preceding the start of the call. We estimate the effects separately at 15, 30 and 60 minutes periods before the call. High organisational slack is defined as periods during which the number of calls per handler was below the median. The sample includes all calls received by the GMP during the second semester of 2011. N=908945 for panel A, N=454077 for panel B and N=454868 for panel C. All regressions include an indicator for whether the call reached the GMP through an emergency line.

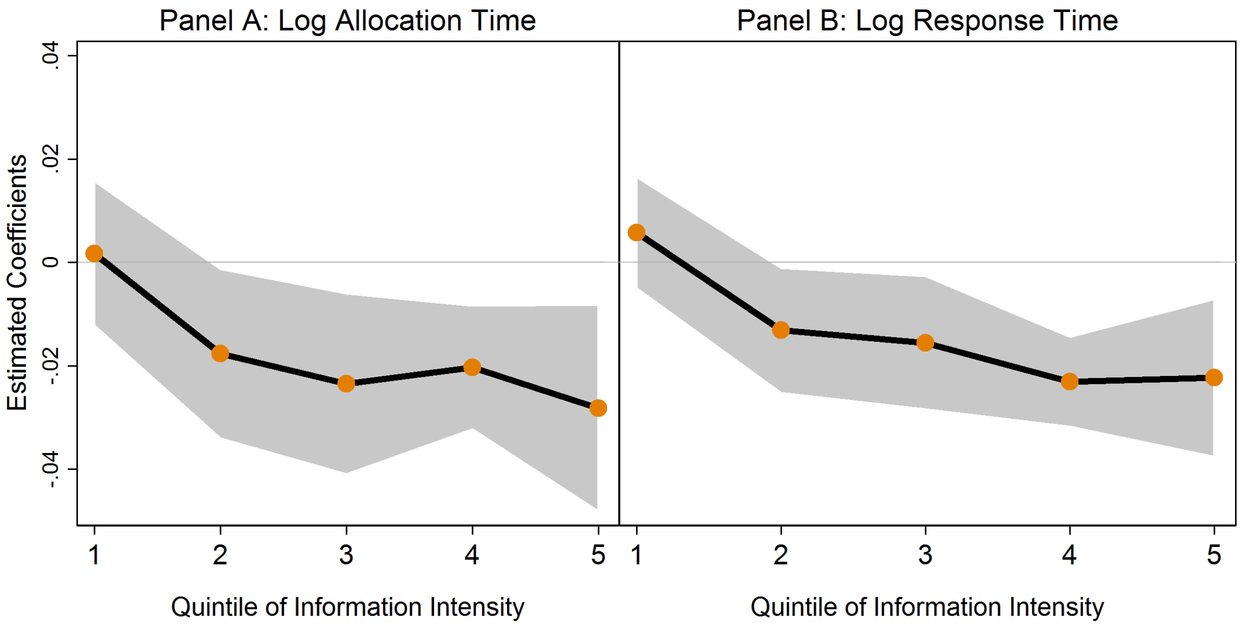
TABLES AND FIGURES FOR ONLINE APPENDIX

FIGURE A1: Balance of Incident, Worker and Room Characteristics on Same Room Incidents



Each row in the figure displays the results of two regressions, where the row variable is the dependent variable and Same Room is the independent variable. The first regression includes only Year X Month X Day X Hour of Day controls and the second regression includes only controls for Radio Operator Room and Call Handler Room. The displayed 95% confidence intervals are for the coefficient of the Same Room variable. Non-binary dependent variables are standardised. Standard errors are clustered at the Year X Month X Radio Operator Room level. Grade 1, Grade 2, Handler Female and Operator Female are the only dummy variables. Handler's Desk Dist. Centre is the euclidean distance between the handler's desk and the centre of the room. Hourly Incidents per Handler in Room is the number of incidents created during the hour of the index incident, divided by the number of handlers working during that hour. A similar definition applies to Hourly Incidents per Operator in Room. Hourly Incidents of Handler is the number of incidents created by the handler in charge of the index incident, during the hour of creation. Hourly Incidents of Operator is the number of incidents allocated by the operator in charge of the index incident, during the hour of the creation of the incident.

Figure A2: Heterogeneity of the Effect of Same Room By Information Intensity of Incident



Each panel displays a different regression. The displayed coefficients are for Same Room X Quintile of Information Intensity. To compute the information intensity variable, we use the sample 2008-2014 and regress the log of creation time (i.e. the time between the handler answering the call and the creation of the incident) on the opening code/grade indicators. We then assign to every opening code/grade incident type its predicted creation time, and split the incident types into quintiles of predicted creation time. 95% confidence intervals are displayed in the shaded grey area. All regressions control for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room X Year, Call Handler Room X Year, Radio Operator Identifier and Call Handler Identifier, and Opening Code/Grade Indicators. Standard error are clustered at the Year X Month X Radio Operator Room level.

TABLE A1: ROBUSTNESS TO CONTROLS

	(1)	(Baseline)	(3)	(4)	(5)
Log Allocation Time	-.023***	-.02***	-.018***	-.019***	-.02***
	(.004)	(.004)	(.004)	(.004)	(.004)
Log Response Time	-.02***	-.017***	-.016***	-.016***	-.017***
	(.003)	(.003)	(.003)	(.003)	(.003)
Hour F.E.	Yes	Yes	Yes	Yes	Yes
Grade/Call Source F.E.	Yes	Yes	Yes	Yes	Yes
Room F.E.	Yes	Yes	No	Yes	Yes
Individual F.E.	No	Yes	No	Yes	Yes
Room/Date F.E.	No	No	Yes	No	No
Individual/Month F.E.	No	No	Yes	No	No
Opening Code/Grade F.E.	No	No	No	Yes	No
Handler Position F.E.	No	No	No	No	Yes

This table displays estimates of OLS regressions of allocation time and response time on whether the call handler and the radio operator re located in the same room. The sample is the basleine sample. Every coefficient is from a different regression. Standard errors clustered at the Year X Month X Operator Room level.

TABLE A2: ALTERNATIVE CLUSTERING

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Panel A: Baseline		
Same Room	-.0201***	-.0172***
	(.004)	(.003)
Panel B: By Handler/Operator Pair		
Same Room	-.0201***	-.0172***
	(.0041)	(.0032)
Panel C: By Subdivision		
Same Room	-.0201***	-.0172***
	(.0039)	(.003)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy. All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A3: HETEROGENEITY OF SAME ROOM BY INCIDENT CHARACTERISTICS PREDICTION WITH OUT OF SAMPLE DATA

	(1)	(2)
Dep. Variable	**Log Alloc. Time**	**Log Response Time**
Same Room	-.001	-.002
	(.009)	(.006)
Same Room X Urgent	-.015	-.006
	(.009)	(.007)
Same Room X Information Intensive	-.024***	-.026***
	(.01)	(.007)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted in measures of the urgency and information intensity of an incident. To compute the information intensity variable we use the post-2012 sample and regress the log of the handler's time to creation (i.e. the time between the handler answering the call and the creation of the incident) on the opening code/grade indicators. We then assign to every opening code/grade incident type its predicted time to creation, and label an incident type as being information intensive if its predicted time to creation is above the median. To compute the urgency variable, we do a similar exercise using the log of the allocation time instead of the log of the handler's time to creation. All regressions also include indicators for Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler, and opening code/grade indicators. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A4: HETEROGENEITY OF SAME ROOM BY INCIDENT CHARACTERISTICS INTERACTION WITH VARIABLES IN LOGS

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Same Room	.081***	.066***
	(.027)	(.02)
Same Room X Non-Urgent	.01***	.006***
(in Logs)	(.003)	(.002)
Same Room X Information Intensive	-.079***	-.064***
(in Logs)	(.021)	(.016)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted in measures of the urgency and information intensity of an incident. To compute the information intensity variable we use the 2008-2014 sample and regress the log of the handler's time to creation (i.e. the time between the handler answering the call and the creation of the incident) on the opening code/grade indicators. We then assign to every opening code/grade incident type its predicted time to creation, and use the variable in logs. To compute the urgency variable, we do a similar exercise using the log of the allocation time instead of the log of the handler's time to creation. All regressions also include indicators for Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler, and opening code/grade indicators. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A5: HETEROGENEITY OF SAME ROOM BY DEMOGRAPHIC DISTANCE (MEDIAN) BY NUMBER OF PAST INTERACTIONS (MEDIAN)

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Same Room	-.0107	-.0093
	(.0093)	(.0071)
Same Room X Same Gender	-.0191***	-.0215***
	(.008)	(.0061)
Same Room X Difference in Age High	.0129	.0125**
	(.0079)	(.006)
Same Room X Number Past Interactions High	-.0005*	-.0001
	(.0003)	(.0002)
Same Gender	-.0027	-.0033
	(.0041)	(.003)
Difference in Age High	.0166***	.0077
	(.0063)	(.0048)
Number Past Interactions High	-.0338***	-.0274***
	(.0049)	(.0038)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted with whether the Radio Operator and the Handler are of the same gender, with their difference in age (measured as an above median dummy), and with the number of previous incidents in which they have worked together (measured as an above median dummy). All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room X Year, Call Handler Room X Year, Radio Operator and Handler. All regressions also control for Handler Experience and Operator Experience. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A6: INVESTIGATING SPILLOVERS ON NON-SAME ROOM INCIDENTS, BY SAME ROOM INCIDENTS

	Spillovers by Same Room Incidents during Period:					
	60 min.		30 min.		15 min.	
Dep. Var	(1) LogAlloc Time	(2) LogResp Time	(3) LogAlloc Time	(4) LogResp Time	(5) LogAlloc Time	(6) LogResp Time
% Same Room Incidents Rece by Operator	.001	.001	-.001	.002	-.004	-.003
	(.006)	(.005)	(.007)	(.005)	(.008)	(.006)

This table investigates potential spillovers from Same Room incidents into non-Same Room incidents. The sample includes only incidents where Handler and Operator were in different rooms (N=734767). The dependent variables in the OLS regressions are log of the allocation time and log of the response time. The independent variable is the percentage of incidents during the index incident time period for which the call handler and the radio operator were located in the same room, excluding the index incident. In Columns (1) and (2) the period comprises of 60 minutes (respectively, 30 minutes for columns (3) and (4) and 15 minutes for columns (5) and (6)). All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. The regressions also include indicators for whether there were no calls received by the Radio Operator during the time period. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A7: ROBUSTNESS TO CONTROLLING FOR THE TIME PERIOD MORE PRECISELY

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Panel A: Baseline (60 minutes)		
Same Room	-.0201***	-.0172***
	(.004)	(.003)
Panel B: 30 minutes		
Same Room	-.0207***	-.0177***
	(.004)	(.003)
Panel C: 15 minutes		
Same Room	-.0198***	-.0179***
	(.0041)	(.0031)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy. All regressions include indicators for Grade, Call Source, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. In Panel A we also include Year X Month X Day X Hour of Day. Panel B substitutes the Hour of Day by the half hour period. Panel C substitutes by the 15 minute period. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A8: CORRELATION BETWEEN MEASURES OF OTHER ACTIONS BY THE HANDLER

Dep. Variable	(1) Log Number of Words	(2) Log Number of Characters	(3) Log Number of Characters
Log Time to Creation	.076***	.076***	
	(.005)	(.005)	
Log Number of Words			.906***
			(0)
Pairwise Correlation	.12	.14	.97

This table displays estimates of the conditional correlation among three actions by the handler during the creation of the incident. The sample includes all incidents received by the GMP between 2008 and 2013 where the dependent and independent variables are available (N=956440). The log of the handler's time to creation is the time between the handler answering the call and the creation of the incident. The number of characters is measured in the first line of the description of the incident (maximum number of characters = 210). The number of words is also measured in the first line of the description of the incident. All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level. The unconditional correlation coefficients are also reported.

TABLE A9: HETEROGENEITY OF SAME ROOM BY INCIDENT GRADE

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Same Room X Grade 1	-.023***	-.013***
	(.005)	(.004)
Same Room X Grade 2	-.016***	-.016***
	(.006)	(.004)
Same Room X Grade 3	-.014	-.013*
	(.009)	(.007)
P-Value G1 $\neq$ G2	.336	.552
P-Value G1 $\neq$ G3	.412	.955
P-Value G2 $\neq$ G3	.885	.722

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted in the Grade of an incident. All regressions also include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A10: ROBUSTNESS TO EXCLUSION OF OUTLYING OBSERVATIONS

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Panel A: Excluding .5%		
Same Room	-.0193***	-.0171***
	(.0039)	(.0029)
Panel B: Excluding 1%		
Same Room	-.0196***	-.0164***
	(.0038)	(.0028)
Panel C: Excluding 5%		
Same Room	-.0174***	-.0136***
	(.0036)	(.0026)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy. All regressions include indicators for Grade, Call Source, Radio Operator Room, Call Handler Room, Radio Operator and Call Handler. In Panel A Column (1) (respectively, Column (2)) we drop from the baseline sample the observations with the .5% highest values of allocation time (respectively, response time). In Panels B and C we do the same for the 1% and 5% highest values. Standard errors are clustered at the Year X Month X Radio Operator Room level.

TABLE A11: HETEROGENEITY OF SAME ROOM BY DISTANCE TO SUPERVISOR DESK

Dep. Variable	(1) Log Alloc. Time	(2) Log Response Time
Same Room	-.055***	-.037***
	(.017)	(.013)
Same Room X Log Distance Handler/Operator	.026***	.018***
	(.009)	(.007)
Same Room X Log Distance Handler/Supervisor	.001	0
	(.008)	(.006)
Same Room X Log Distance Operator/Supervisor	.006	.002
	(.009)	(.007)
Log Distance Handler/Supervisor	.001	.003
	(.005)	(.004)
Log Distance Operator/Supervisor	-.101***	-.061***
	(.014)	(.013)

This table displays estimates of OLS regressions of allocation and response time on the Same Room dummy, interacted with the distance between the handler's desk and the (closest) supervisor's desk, and the distance between the operator's desk and the (closest) supervisor's desk. The interaction with the distance between the handler's desk and the operator's desk is entered as a control. All regressions include indicators for Grade, Call Source, Year X Month X Day X Hour of Day, Radio Operator Room X Year, Call Handler Room X Year, Radio Operator and Handler. Standard errors are clustered at the Year X Month X Radio Operator Room level.

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