When do communication technologies improve the management of innovation?

ABSTRACT

Communication technologies (CTs) have long been viewed as important tools for managing innovation in geographically distant R&D subsidiaries. Yet whether CT-enabled reductions in communication costs between management and R&D subsidiaries actually improve innovation outcomes has remained theoretically and empirically unresolved due to two structural tensions. First, even the most advanced CTs are relatively limited in transmitting tacit knowledge, which is critical for key aspects of innovation management such as monitoring and knowledge-sharing. Second, CTs can enable tighter managerial control over the innovation process, potentially constraining the initiative and creativity that innovation requires. We theorize that whether adoption of a given CT improves R&D subsidiary innovation depends on organizational conditions that mitigate these potential constraints. We test the resulting contingency framework using a unique dataset linking R&D subsidiaries to their managing entities, and exploit the staggered rollout of broadband as an exogenous shock to communication costs. We find that broadband introduction increases R&D subsidiary innovation, but only when (1) the managing entity and R&D subsidiary co-invented prior to adoption, helping overcome the CT's tacit knowledge limitations, or (2) managing entity's span of control is high, limiting the likelihood of increased managerial intervention. Supplemental analyses support the proposed mechanisms. These findings show that CT adoption alone is insufficient to improve innovation. Instead, organizational context shapes whether firms realize the benefits—and minimize the negative consequences—of reduced communication frictions.

Keywords: technology adoption, communication technologies, multinational enterprises, innovation, R&D

1. Introduction

Managing innovation across geographic distance has emerged as a critical organizational challenge in recent decades (e.g., Branstetter et al. 2019, Glaeser et al. 2022). The R&D activities of multinational enterprises (MNEs) have become increasingly geographically dispersed as firms seek to access specialized knowledge and talent (Chung and Alcácer 2002, Zhao 2006, Berry 2014, Berry and Kaul 2015, Branstetter et al. 2019). Yet difficulty communicating with distant R&D subsidiaries hinders essential aspects of innovation management like monitoring and knowledge-sharing (Alfaro and Chen 2018, Glaeser et al. 2022). As a result, MNEs frequently struggle to foster innovation in their subsidiaries (Almeida and Phene 2004, Singh 2008).

Communication technologies (CTs)—wired and wireless technologies that enable written, vocal, and/or visual communication between geographically separated locations (Bloom et al. 2014)—have long been cast as an important tool for tackling this challenge (Aghion et al. 2014, Alfaro and Chen 2018), yet we lack evidence of whether CT-enabled improvements in communication between management and R&D subsidiaries actually enhance innovation outcomes. Prior research shows that CTs facilitate monitoring remote production activities, resulting in productivity gains (e.g., Rangan and Sengul 2009, Berry and Kaul 2015, Alfaro and Chen 2018). Research also shows that CTs improve knowledge-sharing across locations (e.g., Forman and Van Zeebroeck 2012, Forman and van Zeebroeck 2019). However, the distinctive demands of innovation call into question whether these benefits extend to R&D—and even raise the possibility that improved communication between management and distant R&D may inhibit innovation.

There are two key concerns. First, CTs are less effective in transmitting tacit knowledge than codifiable information (Alavi and Leidner 2001, Srikanth and Puranam 2011, Forman and van Zeebroeck 2019), which may limit innovation gains by constraining improvements in monitoring and knowledge-sharing. Monitoring innovation is more dependent on obtaining tacit information than monitoring the standardized production activities examined in prior research (Aghion et al. 2013, Glaeser et al. 2022), and the knowledge from management that is most likely to improve R&D subsidiary innovation outcomes typically contains tacit elements (Allen 1977, Teece 1977, Berry 2015).

Second, research shows that CTs enable managers to assume more control over a distant unit's activities and decision-making (Bloom et al. 2014). Such a shift in control can constrict the initiative and creativity that are essential for successful innovation (Amabile 1988, Holmstrom 1989, Aghion and Tirole 1997, Baker et al. 1999, Zhou 2003, Bernstein 2012). If managers leverage CT-enabled improvements in communication not just to improve evaluation and feedback but to tighten control over the innovation process, R&D subsidiary innovation may even decrease.

Recent findings that, even in an era with advanced CTs, innovation diminishes as distance between management and R&D activity increases (Glaeser et al. 2022) reinforce the need to address these tensions. With global CT expenditures reaching nearly $1.4 trillion in 2024 (Gartner 2025) and advances in CTs like immersive telepresence systems and quantum communication on the horizon, the implications for how MNEs organize innovation and invest in communication infrastructure are significant.

Against this backdrop, we develop a contingency framework for when the introduction of a new CT that improves communication between an R&D subsidiary and the MNE unit responsible for managing it (the managing entity, i.e., the ME) enhances R&D subsidiary innovation.[1] We argue that, on average, CT adoption increases R&D subsidiary innovation through improved monitoring and increased knowledge-sharing, even with limited tacit knowledge transfer. CTs enable MEs to increase the speed, volume, and clarity of codifiable information exchange. They can also enable the transfer of at least some tacit knowledge—by allowing more frequent, informal communication, they facilitate the process of articulation (Nonaka 1994, Nonaka and Takeuchi 1995). These improvements help MEs reduce information asymmetries, allowing them to detect problems earlier, allocate resources more efficiently, and provide more timely feedback. Likewise, the transfer of valuable knowledge from the ME still increases.

[1] Managing entities can be headquarters; secondary, regional, divisional headquarters; or any other subsidiary serving as an intermediate supervisory unit (e.g., Birkinshaw et al. 2006, Zhou 2015, Magelssen 2020, Gumpert et al. 2022, Gillmore et al. 2023).

However, drawing on the knowledge transfer and organizational economics literatures, we argue that the extent to which innovation gains materialize after the adoption of a given CT depends on organizational conditions that influence the impact of the CT's tacit knowledge transfer constraints and the likelihood that MEs tighten control. First, we posit that the effect of adoption is stronger when the CT's tacit knowledge limitations are less likely to constrain improvements in monitoring and knowledge-sharing. One condition under which this is likely is when the ME and R&D subsidiary have co-invented before CT adoption. Research shows that prior collaboration fosters the development of shared context, language, references, and trust, which improves the articulation and transfer of tacit knowledge and makes any persistent gaps in tacit knowledge transfer less consequential (Nonaka 1994, Nonaka and Takeuchi 1995, Hansen 1999, Bechky 2003, Forman and van Zeebroeck 2019). Accordingly, we hypothesize that, for a given CT, R&D subsidiary innovation will increase more when the ME and subsidiary have co-invented before adoption.

Second, we theorize that the effect of CT adoption on R&D subsidiary innovation is weaker when MEs assert more control, stifling the initiative and creativity that innovation demands (Amabile 1988, Holmstrom 1989, Aghion and Tirole 1997, Baker et al. 1999, Zhou 2003, Bernstein 2012). Prior research shows that one condition under which management is more likely to tighten control over a given unit is when management has a low span of control—that is, oversight over relatively few units—because they have greater capacity to direct attention toward the unit (Aghion and Tirole 1997, Baker et al. 1999, Aghion et al. 2014). Therefore, we argue that the risk of MEs tightening control after CT adoption is higher when the ME's span of control is low. By contrast, when ME span of control is high, limited managerial attention serves as a buffer against encroachment as communication costs decrease. CT adoption is therefore more likely to yield the marginal benefits of improved monitoring and knowledge-sharing without undermining R&D subsidiary initiative and creativity. Consequently, we predict that CT adoption will increase R&D subsidiary innovation less when the ME's span of control is low.

Testing these hypothesized relationships presents significant empirical challenges. First, identifying the locus of authority is critical for measuring when a CT reduces communication costs between a ME and R&D subsidiary. This is increasingly difficult as MNE organizational structures become more complex (Aghion et al. 2014). Second, CT adoption, innovation outcomes, and organizational characteristics such as ME span of control or pre-adoption co-invention may be endogenously correlated.

To address the first challenge, we leverage a unique, confidential dataset that links each MNE R&D subsidiary to the organizational unit responsible for managing its innovation activities (the ME). This allows us to observe ME-R&D subsidiary relationships over time with a level of precision that is not feasible through public or purchased datasets.

To address the second challenge, we exploit the staggered, country-level rollout of broadband internet as an exogenous shock to CT adoption. Broadband dramatically reduced communication costs by reducing the cost of data transfer and enabling richer communication modalities like video conferencing for the first time (OECD 2015). Because broadband infrastructure installation was driven by government policy rather than firm choice, and adoption diffused rapidly once available (Ericsson et al. 2013, Bertschek et al. 2013), this setting provides a valuable quasi-experimental context for examining causal effects. We implement a staggered differences-in-differences, intent-to-treat (ITT) design that uses broadband availability—not actual adoption—as the treatment, further reducing endogeneity concerns. An ITT approach is appropriate given the rapid diffusion of broadband once introduced. To test the hypothesized moderators, we apply a triple-difference research design.

The results provide strong support for the proposed contingency framework. On average, R&D subsidiary innovation increases after the introduction of a CT that reduces the cost of communication with MEs. This effect is stronger when MEs and subsidiaries co-invented before CT adoption and weaker when the ME's span of control is low. Strikingly, innovation gains from CT adoption are fully contingent on the presence of one or both conditions: co-invention before adoption or high span of control. Supplemental analyses support the underlying mechanisms. For example, R&D subsidiaries integrate more knowledge from MEs after CT adoption, but only when they had co-invented before adoption. We also find that the span of control moderator is strongest when the time zone difference between ME and R&D subsidiary is small, i.e., when increasing real-time intervention in innovation processes is more feasible. In other words, span of control matters more when the risk that MEs tighten control post-adoption is higher.

This study contributes to several research streams. First, we advance research on CTs and innovation (Agrawal and Goldfarb 2008, Ding et al. 2010, Forman and Van Zeebroeck 2012, Aghion et al. 2014, Alfaro and Chen 2018, Forman and van Zeebroeck 2019) by developing a contingency framework that explains when adoption of a CT that reduces communication costs between an R&D subsidiary and management improves innovation outcomes. We show how that adoption of the same CT can produce different effects depending on whether organizational conditions mitigate the impact of the CT's tacit knowledge transfer limitations on monitoring and knowledge-sharing and limit the risk of tightening managerial control. Second, we contribute to research on firm heterogeneity in the returns to CT investments (Schreyer 2000, Stiroh 2002, Van Ark et al. 2008, Bloom et al. 2012) by demonstrating how differences in organizational context shape the realization of a CT's potential benefits and the mitigation of its potential downsides. Third, we contribute to research on MNE innovation management (e.g., Berry, 2014; Berry & Kaul, 2015; Branstetter et al., 2019; Chung & Alcácer, 2002; Zhao, 2006) by identifying organizational conditions under which CT adoption is most likely to be effective in fostering innovation as MNEs manage increasingly global R&D activities.

As CTs evolve, structuring organizations to unlock their value for managing geographically-dispersed R&D will be increasingly important. Our framework suggests that firms must consider not only whether to adopt new tools but how features of organizational design such as inter-unit relationship history and organizational structure shapes their effects.

2. Theory and Hypotheses

2.1 **Challenges in Managing MNE Innovation**

Managing innovation across geographic distance is a core challenge for MNEs (Chung and Alcácer 2002, Zhao 2006, Berry 2014, Branstetter et al. 2019, Glaeser et al. 2022). R&D

subsidiaries are typically managed by geographically separate entities—e.g., corporate headquarters, regional hubs, or other supervisory units responsible for project selection, oversight, and resource allocation (e.g., Birkinshaw et al. 2006, Zhou 2015, Magelssen 2020, Gumpert et al. 2022, Gillmore et al. 2023). Geographic separation between R&D subsidiaries and MEs makes two essential aspects of innovation management—monitoring and knowledge-sharing—more difficult because they are dependent on frequent, high-quality communication (Allen 1977, Teece 1977, Glaeser et al. 2022).

Monitoring R&D effectively is communication-intensive because R&D activities are highly uncertain and unfold over long time horizons. Since performance cannot be reliably evaluated based on short-term outputs, effective monitoring requires interpreting ambiguous signals and forming nuanced assessments of a project's progress and potential (Manso 2011, Azoulay et al. 2011). These tasks depend on timely updates and contextual understanding developed through frequent dialogue between the ME and R&D subsidiary (Aghion and Tirole 1994, Aghion et al. 2013). Geographic distance hampers such communication by making interpersonal interaction costly (Allen 1977, Glaeser et al. 2022). It becomes especially difficult to access critical "soft" information—unstructured, experience-based insights about a project's viability, risk, and progress that is hard to quantify, often tacit, and highly context-dependent—because transmission is particularly dependent on frequent, informal, unscheduled interpersonal interaction (Scherer 1999, Seru 2014, Liberti and Petersen 2019, Glaeser et al. 2022).

Distance-based communication frictions on monitoring R&D constrain innovation in several ways. Information asymmetries between MEs and R&D subsidiaries about project progress and potential increase, impeding the ability of MEs to detect and deter agency problems such as shirking or championing projects of unclear value in order to secure resources (Robinson 2008, Seru 2014). In response, MEs may hesitate to fund projects, especially those that depend heavily on soft information for accurate evaluation (Robinson 2008, Seru 2014)—even though they are often the very projects that have the greatest potential value to the firm (Fleming 2001, Hall et al. 2005). The risk of project delays and failure also increases because limited visibility into the ongoing efforts and specific challenges of R&D subsidiaries makes it harder for MEs to provide timely and relevant feedback (Manso 2011, Baaij and Slangen 2013).

Beyond monitoring, distance-based communication frictions also impair MEs' ability to share knowledge with R&D subsidiaries. This is a critical aspect of innovation management. MEs serve as knowledge hubs within MNEs, synthesizing insights from across the organization and disseminating them to their subsidiaries (Gupta and Govindarajan 1991, Lunnan and Zhao 2014, Berry 2015). They also hold specialized knowledge and experience that can advance R&D subsidiary innovation efforts (Lunnan and Zhao 2014, Teodorescu et al. 2022). Yet geographic distance limits their ability to play this role effectively. Even relatively codifiable knowledge becomes harder and more costly to transmit as distance increases (Allen 1977, Teece 1977). The challenge is particularly acute for tacit knowledge—such as experiential insights, contextual judgments, and unwritten rules—because it is deeply embedded in practice and experience, making it difficult to communicate through documents or formal instruction (Polanyi 1966, Nonaka and Takeuchi 1995). Extended interpersonal interaction is required (Polanyi 1966, Teece 1977, Nonaka and Takeuchi 1995, Zander and Kogut 1995, Szulanski 1996).

Together, these monitoring and knowledge-sharing challenges make realizing the potential benefits of globally-dispersed R&D difficult. In the next section, we theorize how CTs that reduce the cost of communication between MEs and R&D subsidiaries can help resolve these challenges in a way that enhances innovation outcomes.

2.2 The Effect of Communication Technologies

CTs that reduce the cost of communication between MEs and R&D subsidiaries can increase R&D subsidiary innovation by enhancing MEs' monitoring and knowledge-sharing capabilities. CTs facilitate more effective monitoring in three key ways. First, they enable more frequent and detailed updates on project progress, making it easier for MEs to stay informed. Second, increased communication helps MEs build the contextual knowledge needed to interpret ambiguous signals and assess R&D project viability, risk, and progress accurately. Hard information (e.g., project milestones, quantitative results) can be transmitted more efficiently, while access to soft information (e.g., intuitive judgments, experience-based insights) improves over time through the relationship-building and unstructured dialogue that more frequent, informal interaction makes possible (Scherer 1999, Seru 2014, Liberti and Petersen 2019). Third, CTs enable MEs to provide more timely and relevant feedback through more frequent and unscheduled communication and enhanced contextual understanding.

These monitoring improvements can enhance R&D subsidiary innovation outcomes by enabling MEs to better evaluate progress and effort, making it easier to detect and deter agency problems like shirking or overselling ambiguous projects (Giroud 2013, Glaeser et al. 2022). With more complete information about R&D activities, MEs are more likely to approve and sustain funding for valuable but difficult-to-evaluate projects (Robinson 2008, Seru 2014). More timely and relevant feedback increases the efficiency and probability of success of R&D efforts (Manso 2011, Giroud 2013, Glaeser et al. 2022).

CTs that reduce the cost of communication between MEs and R&D subsidiaries can also improve ME knowledge-sharing. First, they reduce the time and cost barriers that geographic distance imposes on the transfer of codified knowledge (Nonaka 1991, Zander and Kogut 1995, Forman and van Zeebroeck 2019). Second, by lowering the cost of frequent, unscheduled communication, CTs foster relationship-building and the kind of iterative dialogue that supports the transfer of complex, context-rich knowledge. These informal interactions promote trust, social capital, and psychological safety, which are essential for encouraging the sharing of speculative thinking, informal ideas, and insights that might otherwise go unspoken (Edmondson, 1999; Nahapiet & Ghoshal, 2009; Nonaka, 1994). Over time, such interactions also enable the development of shared cognitive frameworks, technical language, and codes of communication that help R&D subsidiaries interpret and integrate knowledge from the ME more effectively (e.g., Argyres, 1999; Carlile, 2004; Cohen & Levinthal, 1990; Nonaka & Takeuchi, 1995). The opportunity for back-and-forth, informal questioning and clarification is particularly important for articulating and integrating complex knowledge (Nonaka 1994, Nonaka and Takeuchi 1995, Tsoukas 2009).

Because CTs that reduce the cost of communication between MEs and R&D subsidiaries enhance monitoring and knowledge-sharing capabilities, we expect that, on average, CT adoption has a positive effect on R&D subsidiary innovation. Therefore:

Hypothesis 1: *R&D subsidiary innovation increases after the adoption of a technology that reduces the cost of communication with its ME.*

However, prior research suggests two potential constraints on the extent to which CT adoption improves R&D subsidiary innovation. First, CTs are limited in their ability to transfer tacit knowledge (Alavi and Leidner 2001, Srikanth and Puranam 2011, Forman and van Zeebroeck 2019). While increasing the frequency of unstructured, iterative dialogue can improve the transfer of some initially tacit knowledge through the process of articulation (Nonaka 1991, Nonaka and Takeuchi 1995), a lot of tacit knowledge still resists articulation and codification, with transfer requiring observation and demonstration (Polanyi 1966). Even advanced CTs like high-quality video conferencing or immersive telepresence systems that support remote demonstration and observation fail to fully convey contextual subtleties, and virtual interactions cannot replicate the opportunities for spontaneous, informal interaction that arise when individuals are collocated—such as hallway conversations or casual observation of colleagues' work—which often serve as key channels for tacit knowledge exchange (Alavi and Leidner 2001, Forman and van Zeebroeck 2019). These limitations may constrain the extent to which CTs enhance monitoring by impeding MEs' access to the tacit elements of soft information. They may also limit knowledge-sharing benefits since the insights from MEs that are most critical for innovation—such as intuitive understandings, uncodified expertise, and complex technical knowledge—are largely tacit in nature (Teece 1977, Gupta and Govindarajan 2000, Berry 2015).

Second, CT adoption may result in more managerial control over an R&D subsidiary's activities (Bloom et al., 2014), which can suppress innovation. While MEs hold formal authority over R&D subsidiaries, the information asymmetries described above often result in subsidiaries exercising substantial "real" authority—where proposals are routinely rubber-stamped and decision-making is informally delegated (Aghion and Tirole 1997, Baker et al. 1999). This autonomy can increase motivation and allow R&D subsidiaries to leverage their informational advantages in the innovation process (Aghion and Tirole 1997, Baker et al. 1999, Acemoglu et al. 2007).

Yet as CTs enable MEs to receive more frequent updates and build contextual knowledge about ongoing R&D efforts, it becomes easier—and more tempting—for them to intervene directly (Aghion and Tirole 1997, Acemoglu et al. 2007, Bloom et al. 2014). Research has indeed shown that CT adoption increases managerial control over decision-making (Bloom et al. 2014). This shift can constrain R&D subsidiary innovation not only by removing decision-making authority from those with the most relevant information and expertise but also by reducing R&D subsidiaries' incentive to initiate or champion novel ideas due to anticipation of being second-guessed or overruled (Aghion and Tirole 1997, Baker et al. 1999, Acemoglu et al. 2007). Management may even intensify scrutiny to the point of removing employee discretion over their own behavior, further diminishing employees' sense of control (Zhou 2003). The result is more conservative approaches, reduced creativity, and, ultimately, weakened innovation outcomes (Amabile 1988, Aghion and Tirole 1997, Zhou 2003, Bernstein 2012).

While different CTs vary in exactly how constrained they are in transmitting tacit knowledge or the degree of managerial control they can ultimately enable, we theorize that the extent to which these constraints limit innovation gains after the adoption of a given CT depends on key features of the organizational context. In the next section, we draw on the knowledge transfer and organizational economics literatures to hypothesize two such contingencies: (1) co-invention by the ME and R&D subsidiary before CT adoption, which mitigates a CT's limitations in tacit knowledge transfer, and (2) the ME's span of control, which moderates the risk that CT adoption leads to tighter managerial control.

2.3 Organizational Contingencies in the Effect of Communication Technologies

The first contingency addresses CTs' limitations in transferring tacit knowledge. We propose that this constraint on the extent to which CT adoption improves R&D subsidiary innovation becomes less binding when MEs and R&D subsidiaries have established a foundation for effective knowledge exchange before CT adoption through collaboration—specifically, in the form of co-invention.

Collaboration through a process like co-invention creates extended periods of interaction that foster the development of shared vocabulary, cognitive frameworks, and assumptions, allowing units to communicate complex ideas with greater economy and precision (Hansen 1999, Carlile 2004, Forman and van Zeebroeck 2019). Of particular relevance for tacit knowledge transfer, such collaboration promotes the creation of specialized language, metaphors, and analogies that help articulate knowledge that might otherwise resist codification (Nonaka 1994, Nonaka and Takeuchi 1995). It also builds mutual trust and psychological safety (Nonaka 1994, Nonaka and Takeuchi 1995, Leonard and Sensiper 1998), which make parties more willing to admit knowledge gaps and to engage in the iterative questioning essential for tacit knowledge exchange (Edmondson, 1999; Nahapiet & Ghoshal, 2009; Nonaka, 1994). Therefore, MEs and R&D subsidiaries that have co-invented prior to CT adoption are more likely to be able to increase tacit knowledge transfer post-adoption, allowing for greater reductions in information asymmetries and greater increases in knowledge-sharing.

Moreover, any persistent gaps in tacit knowledge transfer are less likely to hamper MEs' ability to improve monitoring and knowledge-sharing after CT adoption (Bechky 2003, Srikanth and Puranam 2011). Collaborative experiences create shared contextual understanding and interpretive frameworks that reduce the need for exhaustive knowledge transfer in the first place by enabling units to correctly interpret partial or imperfect knowledge transfers based on their repository of shared experiences and reference points (Bechky 2003).

In contrast, when MEs and R&D subsidiaries have not co-invented prior to CT adoption, a shared relational and cognitive infrastructure is less likely to be in place. The likelihood of misunderstanding, misinterpretation, and failed articulation of crucial tacit elements in the monitoring and knowledge-sharing processes increases. Hence, the same CT adoption may yield weaker improvements in monitoring and knowledge-sharing, limiting innovation gains. Therefore:

Hypothesis 2: R&D subsidiary innovation increases more after the adoption of a technology that reduces the cost of communication with its ME when the R&D subsidiary and ME co-invented *before adoption.*

The second contingency addresses the potential for MEs to tighten control over the innovation process after CT adoption, suppressing improvements in innovation outcomes. We posit that the likelihood of this outcome depends on the ME's span of control.

Research in organizational economics shows that principals with a higher span of control —meaning they oversee more units in the organization—are less likely to increase control over agents' decision-making because the cost of intervention increases with each additional unit under their supervision (Aghion and Tirole 1997, Baker et al. 1999, Aghion et al. 2014). In our context, while CTs may enable MEs to acquire more information and contextual understanding, processing and acting on that information to intervene directly in decision-making and micromanage employee behavior requires significant attention (Aghion and Tirole 1997, Aghion et al. 2014). When span of control is higher at the time of adoption, a ME's finite attention becomes more thinly spread, raising the cost of micromanagement and reducing the likelihood of constrictive control. This attention constraint serves as a safeguard for an R&D subsidiary's sense of autonomy after CT adoption.

Conversely, when a ME oversees relatively few subsidiaries, its attention is less constrained. In such settings, the same CT adoption is more likely to result in tighter control, undermining the initiative and creativity that innovation requires (Amabile 1988, Aghion and Tirole 1997, Zhou 2003, Bernstein 2012), thereby limiting the potential innovation gains from improved communication. Therefore:

Hypothesis 3: R&D subsidiary innovation increases more after the adoption of a technology that reduces the cost of communication with its ME when the ME's span of control at the time of adoption is larger.

3. Methods

3.1 Data

3.1.1 Identifying Managing Entity Relationships for R&D subsidiaries

To test our hypotheses, we must identify which organizational unit within an MNE holds authority over each R&D subsidiary's innovation activities. Yet the structure of management for R&D subsidiary innovation is often described as being stuck inside the "black box" of the firm (Arora et al. 2014). No publicly available or purchased databases identify which entities within the firm manage each R&D subsidiary. While prior work has leveraged patent assignments and surveys to create firm-level proxies of R&D (de)centralization (e.g., Argyres and Silverman 2004, Arora et al. 2014), our analysis requires precise, subsidiary-level identification of authority relationships.

Therefore, we obtained access to a unique, confidential dataset derived from transfer pricing reports from a consulting firm that provides reliable information about which organizational unit with an MNE manages each R&D subsidiary's innovation activities. The data was obtained under a strict confidentiality agreement. All firm specific information is anonymized, and we report aggregate statistics rather than firm-level point estimates. The starting sample includes XXX R&D subsidiaries from all 102 MNEs for which the consulting firm had information available at the time of data collection. The sample period is 1997 to 2011. Although the number of MNEs may appear modest, our sample size is consistent with existing studies that try to identify the units that manage R&D subsidiaries. In particular, (citation needed) performs a survey of R&D management for XXX subsidiaries. Similarly, (citation needed) studies XXXX R&D subsidiaries managed by headquarters.

Our data offers three key advantages. First, international regulations mandate that firms document which entities within an MNE have control rights to R&D subsidiary activities in their transfer pricing reports (OECD 2017).[2] This allows us to identify the MEs for each R&D subsidiary. MNE entities with control rights to R&D subsidiaries are formally responsible for R&D project approval and funding (Roth and Morrison 1992, Aghion and Tirole 1994, Magelssen 2020). They also have incentive to manage R&D subsidiaries effectively—i.e., to monitor innovation progress and to share useful knowledge—because they are entitled to any income

[2] Country governments mandate the reporting of this information, which must follow international standards.

generated from the innovation the R&D subsidiary performs (Roth and Morrison 1992, Aghion and Tirole 1994, Magelssen 2020). Tax authorities have a vested interest in ensuring that the MEs for R&D subsidiaries are appropriately compensated because innovation is a core driver of profitability (EY 2013). They use the transfer pricing reports to verify that MEs their jurisdictions receive the appropriate income.

Second, the information in transfer pricing reports is highly reliable. The ME control rights are documented and verified based on written contracts between MNE entities (see example contract clauses in Appendix A), payment and transaction flows, and interviews with management detailing roles, responsibilities, rights, and activities (OECD 2017). The reports are audited and are used in court cases. Inaccurate information can result in stiff penalties and criminal charges (EY 2013).

Third, each report includes information about the intra-firm activities for at least three years, allowing us to account for organizational and institutional changes.

We code subsidiary A as the ME for R&D subsidiary B at time t if the transfer pricing report shows that R&D subsidiary B was under the control of subsidiary A or contracted to perform R&D on behalf of subsidiary A (see Appendix A for a sample excerpt from one of these reports).

3.1.2 Introduction of Broadband

Broadband is defined as high-speed access to the public Internet (a TCP/IP connection) at downstream speeds equal to, or greater than, 256 Kbit/s (OECD 2015). We collect data on fixed broadband subscriptions from the World Bank's World Development Indicators, which measures market penetration as the percentage of fixed broadband subscriptions in the population (businesses and residences). Fixed broadband provides high-speed access to the public Internet in fixed locations using technologies such as cable modem, digital subscriber line (DSL), fiber optic, satellite, fixed wireless, and broadband over power lines (BPL).

Broadband introduction provides an ideal empirical setting for our study for two reasons. First, broadband radically reduced communication costs between geographically separate locations (OECD 2015). Compared to pre-broadband technologies like dial-up Internet (which was limited to 56 Kbit/s), broadband offered dramatically faster data transfer speeds (OECD 2015). It also enabled simultaneous two-way communication and—for the first time—functionality like real-time, high-quality video conferencing (Ezell et al. 2009, Ericsson et al. 2013, OECD 2015). Even if large companies had installed wide area networks (WANs) or private intranets before broadband, their speed and functionality were ultimately constrained by the country's infrastructure; private installation of broadband was prohibitively costly for firms (Majumdar 2019, De Wit 2022). Thus, introducing a broadband connection between an ME and R&D subsidiary significantly reduced the cost of the kind of frequent, spontaneous, real-time, rich communication that is essential for managing innovation and would have previously required in-person interactions.

Second, broadband introduction provides a quasi-experimental setting for examining causal effects. Government policy rather than firm-level decisions drove the installation of broadband infrastructure, motivated by its significant economic and social impact (OECD 2015). The European Commission, for example, aimed for 100% broadband coverage in every EU country by 2013 (OECD 2015). Installation of broadband infrastructure began in the early 2000s. By 2011, broadband infrastructure was available in 85% of countries in our sample. Firms rapidly adopted broadband once it became available due to its low implementation costs and potential for significant productivity gains (Antonelli 2002, Bertschek et al. 2013, OECD 2015). Hence, broadband adoption was primarily driven by its exogenous availability, and the rapid adoption once available allows us to use an intent-to-treat (ITT) design—where treatment is based on broadband availability, not actual adoption—which further reduces endogeneity concerns (Angrist and Pischke 2008). Additionally, the staggered nature of the introduction of this technology across countries allows us to substantially mitigate concerns about time-varying institutional factors that could confound the relationship between R&D subsidiary innovation and broadband introduction.

3.1.3 Innovation Data

We measure innovation using patents, a widely recognized and externally validated indicator of technological novelty commonly used in studies of firm innovation (Griliches 1990, Lerner and Seru 2017). While patents reflect only a subset of innovation activity, they offer a consistent and comparable measure across firms, industries, and time periods. We source patent data, including inventor locations, assignees, forward and backward citations, and technological classes, from the United States Patent and Trademark Office (USPTO).

Using patent data from a single patent authority is standard practice due to variations in application procedures, examination standards, and disclosure requirements across different patent offices (Berry 2014). We chose the USPTO data for this study because it consistently reports inventors' addresses throughout our sample period, which is necessary for us to identify the inventing subsidiary for each patent. Other major patent offices either did not collect or systematically report inventor locations or only required identification of a single inventor.

While using the USPTO data has limitations—in particular, it may potentially bias the results toward U.S. subsidiaries—this bias is mitigated by the fact that all MNEs in our dataset have at least one U.S. location, and firms active in the U.S. market have strong incentives to file with the USPTO regardless of invention location. To assess the potential bias, we conduct robustness tests by separately analyzing R&D subsidiaries located in the U.S. and those outside the U.S., and find consistent results in both cases, alleviating these concerns.

To construct our innovation panel, we searched the USPTO database for all granted patent applications assigned to each MNE or any subsidiary within the MNE group.[3] Our search included the full legal entity name and variations of the root name, incorporating suffixes such as “Inc.,” “Corporation,” “A.G.,” and “SAS.” In cases of ambiguity regarding the corresponding MNE or subsidiary, we verify the assignee address to ensure it corresponds to one of the MNE’s known addresses. This process yields 50,934 patents.

We then match these patents to specific MNE entities based on inventors’ city, state, country, and filing year. We use the filing date rather than grant date because it more closely corresponds to the actual time of invention (Lerner and Seru 2017). For cases with multiple MNE entities in the same city, we match patents based on overlap between assignee and MNE entity names. When MNE entities have similar root names, we match based on the technological focus of the entity.

[3] We use the algorithms from https://www.leydesdorff.net/indicators/ to download the patent data.

For example, if two pharmaceutical subsidiaries conduct R&D on drugs, a patent for an oncological drug is linked to the subsidiary focused on oncological research.

Our final dataset includes 29,028 patents with a single inventor, 10,711 patents with multiple inventors from the same MNE entity location, and 11,195 patents with inventors from multiple MNE-entity locations.

3.5 Sample

The starting sample is composed of 102 MNEs over the 1997-2011 period. Since our study is focused on the management of geographically-distant R&D subsidiaries, we eliminate MNEs without foreign R&D activities and R&D subsidiaries that are autonomous—i.e., manage their own R&D activities. This reduces the sample to 78 MNEs and their 1,004 managed R&D subsidiaries, accounting for 4,395 subsidiary-year observations. While these MNEs operate across a broad range of industries, the majority are in manufacturing. Approximately 78% of the MNEs are headquartered in North America, 19% in Europe, and the remainder in Asia.

We observe that ME-R&D subsidiary relationships are highly stable over time, reflecting the significant adjustment costs and regulatory scrutiny that MNEs face when transferring control rights within the firm (OECD 2017).(add footnote on adjustment costs?) Only 96 of the 1,004 R&D subsidiaries experience a change in ME during the sample period—most commonly around the 2008 financial crisis—and only 79 occurred in or after the year of broadband introduction. For ME changes occurring after broadband introduction, the time between introduction and ME change ranges from zero to eight years with a mean and median of four years.

We retain the R&D subsidiary in the sample as long as its management remains unchanged. To ensure that ME changes do not confound our analysis of the effects of broadband, we drop R&D subsidiaries from the sample when their ME changes (year during and post change). This approach eliminates 155 subsidiary-year observations. Seven subsidiaries were dropped from the sample due to the timing of their changes coinciding with the year of broadband introduction. This process reduced the sample to 997 subsidiaries and 4,240 subsidiary-year observations across.

We also exclude four subsidiaries (16 subsidiary-year observations) that license technologies from another MNE entity to avoid conflating intra-firm management effects with licensing relationships. Consistent with prior research (e.g., Zhou 2015), we exclude 47 subsidiaries (215 subsidiary-year observations) with pure tax haven management relationships—where MEs are located in tax havens without operations. The resulting sample has 3,999 R&D subsidiary-year observations for 945 R&D subsidiaries. The majority of these R&D subsidiaries (688 in total) have a single ME (as opposed to multiple MEs that oversee different projects), accounting for 2,609 R&D subsidiary-year observations.

We assess the generalizability of our dataset in two ways. First, we gather data from Orbis for the 2,000 largest MNEs worldwide based on 2011 revenue. After removing MNEs in agriculture, mining, banking, and public administration because these industries generally do not innovate and are not in our focal sample, the MNEs in our sample show no significant differences in firm size ($p=0.19$) or R&D intensity ($p=0.13$ among firms that report R&D expenditures) compared to the Orbis MNEs ranked 1,150-2,000. Thus, our sample represents relatively large MNEs, though not the very largest companies globally. Second, we compare our dataset with the data used in (Berry 2014), which comprises a confidential panel of MNE R&D subsidiaries from the Bureau of Economic Analysis. We find no significant differences in MNE size ($p=0.17$), the proportion of foreign subsidiaries performing R&D (16.9% in our data vs. 18.2% in (Berry 2014)), or in the average annual patents per MNE ($p=0.29$).

3.6 Variables

Dependent Variable. The main dependent variable in our analysis is *Innovation Quantity*, measured as the natural log of one plus the total number of successful filed patent applications by the R&D subsidiary's inventors each year. In robustness analyses, we also use *Innovation Market Value*, measured as the MNE market-adjusted returns in millions of dollars within three days following a patent's issue date for the patents invented by the focal R&D subsidiary in that year, adjusted to 1982 dollars (Kogan et al. 2017). We obtained this measure from the Kogan database, which covers 61.1% of all patents in our sample.[4] Innovation market value captures the anticipated commercial value of the innovation (Kogan et al. 2017). We use the natural log of one plus the market value of the patents applied for in a given year.

Independent Variables. Our main independent variable of interest is *Post-Broadband Introduction*, a binary variable set to 1 starting the year after broadband penetration reaches 5% in the countries of both the R&D subsidiary and the ME. We set a 5% market penetration rate as the threshold for broadband introduction based on specialist studies and test alternative thresholds in robustness tests to ensure consistency (Ezell et al. 2009, Mack-Smith 2013). Research indicates that, even at low penetration rates, the availability of communication infrastructure can significantly enhance firm productivity (Roller and Waverman 2001). Moreover, broadband is generally first introduced in urban and industrial centers where firms are typically located (citation needed), and therefore having a higher penetration rate can cause units that are actually "treated" to be coded as "untreated" in the analyses. The average country in our sample reaches this 5% threshold two years after the start of our observation period (median is 2 years). We require both the R&D subsidiary and the ME to reach the 5% threshold since communication costs decrease most significantly when both parties have access to broadband (Forman and van Zeebroeck 2019). We examine the effect of R&D subsidiary broadband access only in supplementary analyses.

We identify co-inventions by each ME and R&D subsidiary by matching patents that list inventors from both the ME and R&D subsidiary locations in the same year. We construct a binary variable, *Pre-Treatment Co-invention with ME*, equal to 1 if the ME and R&D subsidiary have at least one co-invented patent in the five years before the treatment year (broadband introduction) and zero otherwise.

We compute each ME's span of control as the total number of R&D subsidiaries controlled by the ME (Rajan & Wulf, 2006; XXX(Francisco study)). We then create a binary indicator for *Pre-Treatment High ME Span of Control*, coded 1 if the ME's span of control is at or above the sample

[4] See Kogan et al. (2017) for details on the conditions under which market values are not estimated.

median (XXX state median) in the year prior to broadband introduction, and 0 otherwise. ME span of control is highly stable, with (XXX) changes within three years of broadband introduction.

We operationalize these moderators of interest as binary variables because it facilitates cleaner interpretation of heterogeneous treatment effects in a difference-in-differences-of-differences (DDD) framework, allowing us to compare post-broadband changes in innovation between distinct subgroups (e.g., with vs. without co-invention).

Control Variables. Because our DD and DDD analyses include R&D subsidiary and year fixed effects, our controls are limited to variables that vary across time and subsidiaries that may confound the relationship between broadband introduction and changes in innovation quantity. We include the *Revealed Technological Advantage (RTA)* index from the OECD online database that captures each host country-industry's technological specialization (Almeida 1996) to account for the possibility that broadband introduction is correlated with changes in a host country's technological capabilities. To account for the possibility that broadband introduction may be correlated with competitive conditions that may drive changes in innovation, we use the Global Vantage database to calculate the host country-industry *Market Concentration Index* as the sum of the proportion of total revenues earned by the four largest firms in the host country-industry location. To control for the level of CT infrastructure between ME and R&D subsidiary pre-treatment and that locations that are more developed may receive infrastructure earlier than those that are less developed, we incorporate the *Global Connectivity Index* from Berry (XXXX) for the year before broadband introduction interacted by year. [clarify this definition]

We use Orbis data to control for key MNE characteristics. We measure *MNE Size* as the natural log of MNE revenues. *MNE Diversification* is based on an entropy measure of the MNE's share of total sales in each business segment each year (Palepu 1985). We also include the natural log of total *MNE Stock Compensation* expense, which can affect the incentive to innovate (Oxley and Pandher 2016).[5]

[5] We calculate an MNE-level measure because subsidiary-level stock compensation data and managerial incentive data are unavailable.

We account for the possibility that broadband introduction is correlated with changes in R&D subsidiary roles and responsibilities using qualitative data about each subsidiary's mandates from the transfer pricing reports (e.g., R&D, manufacturing, distribution and service). Following prior research (Fey and Furu 2008), we code *Subsidiary Role* as the count of the number of mandates.

3.7 Estimation

We employ a staggered difference-in-differences (DD) intent-to-treat (ITT) approach to assess the effects of broadband introduction on R&D subsidiary innovation output. The DD model estimates changes in innovation output for treated R&D subsidiaries (those exposed to broadband) relative to changes in innovation output for control R&D subsidiaries (those not yet exposed to broadband) at that point in time. Our baseline specification is:

$$Y_{¿+1} = \beta_0 + \beta_1 PostBroadbandIntroduction_{ct} + \beta_2 X_{\mathrm{it}} + \alpha_i + \gamma_t + \varepsilon_{\mathrm{it}} \tag{1}$$

where $Y_{¿+1}$ represents the innovation quantity produced by subsidiary i in year t+1. The variable *Post-Broadband*$_{ct}$ is the binary indicator for *Post-Broadband Introduction* explained in Section 3.6. The coefficient of interest, β_1, represents the average treatment effect of broadband introduction on R&D subsidiary innovation. The vector X_{it} includes control variables for the subsidiary, host-country-industry, and the MNE. We add subsidiary, α_i, and year, γ_t, fixed effects to control for time-invariant subsidiary characteristics and unobservable factors that may affect innovation in a given year.

We use a one year lag structure to mitigate concerns about simultaneity or reverse causality. This also reflects that changes in innovation output following CT adoption are likely to take time to manifest. Since *Post-Broadband Introduction* is coded as equal to one in the year after both the R&D subsidiary and ME reach the broadband penetration threshold, β_1 represents the change in innovation quantity two years after broadband introduction reached the threshold. Standard errors are clustered at the subsidiary level.

Next, we employ a triple difference (DDD) analysis to test whether the estimated effects of broadband differ based on *Pre-Treatment High ME Span of Control* and *Pre-Treatment Co-invention with ME*. The DDD modifies the DD specification above as follows:

$$Y_{i,t+1} = \beta_0 + \beta_1 PostBroadbandIntroduction_{ct} + \beta_3 \left(Z_{\text{it}} \times PostBroadbandIntroduction_{ct} \right) + \beta_2 X_{\text{it}} + \alpha_i + \eta_{\text{it}} + \gamma_t + \varepsilon_{\text{it}} \quad (2)$$

Z_{it} represents the moderator of interest (either *Pre-Treatment High ME Span of Control* or *Pre-Treatment Co-invention with ME*), which is interacted with $PostBroadbandIntroduction_{ct}$. We also include η_{it}, which is an interaction of Z_{it} with year-fixed effects, to isolate the triple differences (Pischke 2005). β_3 captures the additional effect of broadband introduction for R&D subsidiaries whose MEs had a high span of control (or co-invented with the R&D subsidiary) before treatment, relative to subsidiaries whose MEs did not. This is a difference-in-differences of differences (DDD) estimate: the difference-in-difference estimate of the effect of broadband on innovation quantity for R&D subsidiaries with high ME span of control (or pre-treatment co-invention with ME) before broadband introduction minus the DD estimate for R&D subsidiaries with low ME span of control (or no pre-treatment co-invention with ME). β_1 captures the average effect of broadband introduction for subsidiaries with low pre-treatment ME span of control or no pre-treatment co-invention.

We conduct supplemental analyses to address potential biases that may arise with staggered difference-in-differences research designs (e.g., De Chaisemartin and d'Haultfoeuille 2020a, Callaway and Sant'Anna 2021, Goodman-Bacon 2021a, Baker et al. 2022).

3.8 Descriptive Statistics

Table 1 details the distribution of R&D subsidiaries by country location and broadband introduction year for the country location. Our sample includes R&D subsidiaries located in 53 countries, with the United Kingdom and United States representing the largest concentrations of 12.78% and 21.21%, respectively. MEs are highly concentrated in XX, XX, and XX countries. Broadband technology was introduced in countries between 2000 and 2015, with a median country introduction year of 2004.

------Insert Tables 1 and 2 about here------

Table 2 provides detailed descriptive statistics. The mean annual innovation quantity (logged patent count) is 0.41 patents per year with standard deviation of 0.83. For the sample of R&D

subsidiaries with one ME, the mean annual innovation quantity drops to 0.22 per year and has a lower standard deviation of 0.56. In other words, on average, R&D subsidiaries produce 0.51 patents per year in the full sample, and 0.24 patents per year in the sample with only one ME. The mean R&D expense is $4.53 million ($4.88 if R&D subsidiary has only one ME).

On average, MEs are located 4,837 miles from their R&D subsidiaries, with distances ranging from 9.56 to 19,147 miles. The average distance between MEs and their R&D subsidiaries in the one ME only sample remains relatively consistent at 4,372 miles. The mean ME span of control pre-treatment is 14.62 (14.89 if the R&D subsidiary has only one ME) meaning the average number of R&D subsidiaries under the control of the focal R&D subsidiary's ME at the time of broadband introduction is 14.62. The mean number of co-invented pre-treatment by the focal R&D subsidiary and ME is 0.84 (0.64 if the R&D subsidiary has only one ME). XX% of R&D subsidiaries had at least one co-invention pre-treatment.

The average MNE in our dataset reports total revenues of $XXX billion and stock compensation expenses of $XXX million. To maintain the confidentiality of company-specific data, only aggregated statistics (and not firm-specific minimum and maximum values) are presented for these variables.

4. Results

Table 3 presents the main results. Column 1 shows the DD results for the full sample without the R&D subsidiary, MNE, and country-industry control variables. Column 2 incorporates the control variables. Columns 3 and 4 show the DD results without and with control variables for the sample of R&D subsidiaries with only one ME. In support of Hypothesis 1, the results in Columns 1-4 indicate that broadband introduction has a positive and statistically significant ($p<0.001$) effect on R&D subsidiary innovation quantity, i.e., natural log of the number of patents. The results remain consistent across various thresholds of broadband penetration (3.0%, 7.0%, and 9.0%), as shown in Appendix B (Table B.1), suggesting our findings are not sensitive to the specific definition of broadband introduction.

Interpreting the coefficient in Table 3 Column 4 as a semielasticity, the introduction of broadband is associated with a 15.0% increase in the number of patents generated in a given year. The estimate for the full sample in Column 2 is virtually the same. Since the estimates are so similar, we report the remaining results for the sample of R&D subsidiaries with one ME because it offers a cleaner evaluation of how the introduction of a broadband connection between an R&D subsidiary and ME affects innovation.

Next, we examine whether the effects of broadband introduction vary based on the organizational contingencies proposed in Hypotheses 2 and 3, shown in Columns 5-7. In Column 5, the coefficient on *Post-Broadband Introduction* is 0.096 (p=0.009), which, using the semi-elasticity transformation, corresponds to a 10.1% increase in patents for R&D subsidiaries that did *not* co-invent with the ME before broadband. The coefficient on the interaction between *Pre-treatment Co-invention with ME* and *Post-Broadband Introduction*. is 0.338 (p=0.030), supporting Hypothesis 2 that the effect of broadband is larger for R&D subsidiaries that *did* co-invent with the ME before broadband. These R&D subsidiaries experience a 54.3% increase in patents—44.3 percentage points higher than R&D subsidiaries that did not co-invent with the ME pre-treatment..

Column 6 includes the interaction between *Pre-treatment High ME Span of Control* and *Post-Broadband Introduction*. The coefficient on *Post-Broadband Introduction* is 0.070 (p=0.119), indicating the effect of broadband is not statistically distinguishable from zero for R&D subsidiaries whose MEs have a *low* span of control. The coefficient on the interaction term is 0.195 (p=0.013), supporting Hypothesis 3 that the effect of broadband is larger when the ME has a high span of control. These R&D experience a 30.3% increase in number of patents.

Column 7 includes both moderators, with results remaining substantially similar to the estimates in Columns 5 and 6. This stability suggests that the two contingencies operate through distinct mechanisms, as predicted by our theoretical framework. Moreover, when the R&D subsidiary has not co-invented with the ME before adoption and the ME has low span of control, the effect of broadband is small and not statistically distinguishable from zero. This suggests that broadband introduction only leads to improved innovation when R&D subsidiaries have co-invented with the ME before broadband and/or the ME has a high span of control.

4.1 Staggered Difference-in-Differences Specification Tests

4.1.1 Parallel Trends and Placebo Tests

The DD estimator requires a parallel trends assumption for causal interpretation: the treated and untreated units follow parallel trends pre-treatment and would have continued to follow parallel trends in the absence of treatment. To assess the validity of this assumption, we follow common practice and estimate an event study specification using relative time indicators. As shown in Figure 1, event-time coefficients for the three years prior to broadband are close to zero and not statistically significant, while post-treatment coefficients become more positive and statistically significant. In other words, the difference in innovation quantity between treated and untreated R&D subsidiaries is statistically indistinguishable from zero pre-treatment and significantly positive post-treatment. These results support the validity of the parallel trends assumption—that treated and untreated R&D subsidiaries would have followed similar innovation trajectories in the absence of broadband—and suggest a causal relationship between broadband introduction and increased innovation.

----Insert Figure 1 about here----

To further assess the validity of the parallel trends assumption and to rule out anticipation effects, we estimate placebo regressions that assign false treatment dates one, two, and three years prior to actual broadband introduction. As shown in Appendix A (Table A.1), all coefficients are small and statistically indistinguishable from zero, reinforcing that our results are not driven by anticipation effects or pre-existing differences in innovation trends.

4.1.2 Heterogeneous Treatment Effects

Recent research has shown that estimates from two-way fixed effects (TWFE) staggered difference-in-differences (DD) models can be biased when treatment effects vary across units or over time (e.g., De Chaisemartin and d'Haultfoeuille 2020a, Callaway and Sant'Anna 2021, Goodman-Bacon 2021a, Baker et al. 2022). The core issue is that TWFE assumes homogenous treatment effects and continues to use already-treated units as if they were untreated controls for other units (De Chaisemartin and d'Haultfoeuille 2020b, Goodman-Bacon 2021b). When these comparisons are aggregated along with treated-versus-actually-untreated comparisons into the single TWFE DD estimate, the weights assigned to the treated-versus-already-treated units can be negative or non-representative (Goodman-Bacon 2021b). As a result, the DD estimate can be biased—even generating negative DD estimates when all actual underlying treatment effects are positive.

This issue is potentially relevant in our setting where heterogeneous treatment effects are plausible due to, for instance, differences in baseline infrastructure and access to complementary technologies across units and/or over time. To address this concern, we use heterogeneity-robust the estimator developed by de Chaisemartin et al. (2024). This estimator avoids using already-treated units as controls and flexibly allows treatment effects to vary by unit and time period. It also generates dynamic treatment effects by comparing changes in outcomes between units treated ℓ years prior with those not-yet-treated and/or never-treated.

As shown in Appendix C Table C.2, the average treatment effect across all post-treatment periods is positive and statistically significant (coefficient = 0.087, p=0.045), consistent with the main results in Table 3. While the dynamic treatment effects vary modestly in magnitude, a joint test does not reject the null that these effects across post-treatment years are equal (p = 0.170), suggesting relatively stable effects over time. Additionally, placebo tests show no evidence of differential pre-trends: the joint test of pre-treatment effects across the three years before treatment is not statistically significant (p = 0.337), consistent with the placebo tests reported in Appendix C Table C.1.

4.2 Isolating Communication Effects between MEs and R&D Subsidiaries

A potential concern is that the observed effects of broadband may not be the result of reduced communication costs between MEs and R&D subsidiaries specifically, but broader technological improvements enabled by broadband access. For example, broadband might enhance innovation by enabling R&D teams to access external knowledge or process internal information more effectively, independent of communication with MEs (Akerman et al. 2015, Wu et al. 2020).

To address this concern, we redefine treatment as broadband availability in the R&D

subsidiary's country alone (still using the 5% penetration threshold), and we restrict the sample to observations where the ME has not yet gained access to broadband. This isolates the effect of broadband adoption by the R&D subsidiary in the absence of any change in communication infrastructure on the ME side (Forman and van Zeebroeck 2019). Results in Appendix D Table D.1 show that the estimated effect of an R&D subsidiary gaining access to broadband under these conditions is negative and statistically indistinguishable from zero. The coefficient on the interaction with *Pre-treatment Co-invention with ME* remains positive but statistically indistinguishable from zero. The interaction with *Pre-treatment High ME Span of Control* is now negative and also indistinguishable from zero.

This pattern reinforces our interpretation that the innovation gains observed in the main analysis stem from improved communication between MEs and R&D subsidiaries (Forman and van Zeebroeck 2019). It also aligns with our theoretical arguments that the moderating effects of co-invention and span of control operate specifically when communication with the ME improves.

4.3 Probing the Mechanisms

We now explore the mechanisms through which broadband introduction affects R&D subsidiary innovation. In our theoretical framework, innovation quantity may increase after broadband adoption due to enhanced monitoring and improved knowledge-sharing. Yet the extent of this increase depends on two key organizational conditions. First, the increase will be larger when an R&D subsidiary and ME co-invented before broadband introduction because prior co-invention helps overcome broadband's limitations in tacit knowledge transfer by instilling a shared context, language, reference set, and trust. Second, the increase in innovation will be larger when the ME has a high span of control because a higher span of control reduces the risk of managerial asserting greater control over innovation activities post-broadband, preserving subsidiary initiative and creativity.

While our main results support this framework, alternative explanations remain possible. One is that the moderating effect of *Pre-treatment Co-invention with ME* arises not from shared experience but from pre-existing technological similarity that both facilitates co-invention and helps overcome broadband's tacit knowledge limitations. To address this possibility, we include *Pre-Treatment ME Technological Distance*, interacted with year, in Appendix E Table E.1 Columns 1-2. *Pre-Treatment ME Technological Distance* is [add definition here]. The positive moderating effect of co-invention persists—and becomes slightly stronger—providing confidence that pre-treatment co-invention itself, not underlying technological similarity, is the relevant mechanism.

We next address an alternative explanation for the moderating effect of *Pre-Treatment High ME Span of Control*. Specifically, MEs with high span may offer greater access to valuable knowledge—broadband may improve innovation more because high span of control enables access to a larger knowledge base rather than because it limits managerial control. Therefore, in Appendix E Table E.1 Columns 3-4, we control for the knowledge stock of the other R&D subsidiaries under an ME's control, interacted with year. *Pre-treatment Managing Entity Span of Control Knowledge Stock* is measured as the number of patents filed by other R&D subsidiaries under control of the focal R&D subsidiary's ME. The coefficient on the interaction between *Post-broadband Introduction* and *Pre-treatment High ME Span of Control* remains stable, suggesting that our findings are not driven by greater knowledge exposure.

Together, these analyses bolster our interpretation that co-invention and span of control moderate broadband's effects through our proposed mechanisms—by influencing how improved communication affects knowledge exchange and control—rather than by proxying for other organizational or technological conditions. We now further probe these mechanisms through additional empirical tests.

4.3.1 Time Zone Distance

We begin by examining whether the effect of broadband on R&D subsidiary innovation differs when the time zone distance between an R&D subsidiary and ME is small versus large. Because synchronous communication is more feasible when time zone distance is small (Cummings et al., 2009; Espinosa & Carmel, 2003; Mell et al., 2021), the potential for richer oversight, feedback, and knowledge-sharing post-broadband is larger. At the same time, the risk of MEs tightening control is also higher as it is more feasible for MEs to increase real-time intervention in the innovation process. Thus, if our theoretical framework holds, the potential effect of broadband should be larger when time zone distance is smaller, but the moderating role of ME span of control should be more pronounced.

Results in Table 4 support this prediction. We calculate time zone distance based on XXX. Columns 1-4 display estimates when time zone distance is high, i.e., when the time zone distance between R&D subsidiary and ME is greater than the sample median (greater than XXX hours). Columns 5-8 display estimates when time zone distance is below the sample median. Columns 1 and 5 exclude the moderator and show that the effect of broadband on innovation quantity is positive regardless of time zone distance. The estimated effect of broadband is slightly higher when the time zone distance is high. However, consistent with our theory, Columns 3 and 7 show that the interaction between *Post-broadband Introduction* and *Pre-treatment High ME Span of Control* is stronger and more statistically significant when time zone distance is low. Moreover, the estimated effect of broadband is largest when time zone distance is low and the ME has a high span of control pre-treatment.

We also include the moderating effect of *Pre-treatment Co-invention with ME* in Columns 2, 4, 6, and 8, though the mechanism by which should vary with time zone distance is less theoretically clear than for span of control. On one hand, the shared context, language, and trust developed through prior co-invention may be especially useful when synchronous communication is limited. On the other hand, these benefits may be most impactful when paired with the ability to engage in real-time dialogue. Further complicating the role of time zone distance for this moderator, knowledge-sharing may be more amenable to “time shifting” in which employees in different time zones shift communication to outside work hours, rendering time zone distance less relevant (Chauvin et al. 2024). The results reflect this ambiguity: the coefficient on the interaction between *Post-broadband introduction* and *Pre-treatment Co-invention* is slightly larger when time zone distance is high, though the difference is modest and the estimate is less statistically robust.

In sum, Table 4 provides compelling support for our arguments that ME span of control moderates the effect of broadband by reducing the risk of ME tightening control over R&D subsidiaries' innovation activities. We continue to probe the moderating role of pre-treatment co-invention in the next section.

4.3.2 Knowledge Flows and Prior Co-invention with ME

Our theory suggests that pre-treatment co-invention with the ME moderates broadband's effect by mitigating its limitations in tacit knowledge transfer. One way this may operate is by improving the subsidiary's ability to access and integrate knowledge from the ME once broadband enables richer communication. If this mechanism is operating, we should observe larger increases in knowledge flows from MEs to R&D subsidiaries when they have co-invented before broadband.

To examine this possibility, we measure *Knowledge Flows from the ME* as the natural log plus one of the annual number of backward citations (excluding examiner citations) to the ME's prior art that the R&D subsidiary had not cited in the prior five years (Singh 2005, Sorenson et al. 2006). Backward citations are widely used as a proxy for knowledge flows (e.g., Sorenson et al. 2006b, Forman and van Zeebroeck 2019, Bahar et al. 2023).

Table 5 Columns 1-6 show estimates for the relationship between broadband and knowledge flows. Column 1 shows that the effect of broadband positive but not statistically significant. Column 2 includes the moderating effect of *Pre-treatment Co-invention with ME*, which is positive, as predicted, but weakly significant (p=0.075). Columns 3-6 show the split-sample analyses by time zone distance. The moderating effect is much stronger and more statistically significant (p=0.007) when time zone distance is low, suggesting that prior co-invention's role in facilitating knowledge transfer post-broadband may be especially relevant when synchronous communication with the ME is more feasible.

Taken together, Columns 1-6 support our argument that pre-treatment co-invention increases the effect of broadband by improving knowledge transfer. However, *Knowledge Flows from the ME* is unlikely to capture all knowledge exchange between R&D subsidiaries and MEs. Therefore, we also examine how the moderating effect of *Pre-treatment Co-invention with ME* on the relationship between broadband and innovation quantity varies by technological distance. If prior co-invention compensates for broadbands tacit knowledge transfer limitations by fostering shared interpretive frameworks, language and context then it should play a stronger moderating role when technological distance between R&D subsidiary and ME is greater—that is, when shared interpretive frameworks, language, and context are less likely to exist in the absence of prior co-invention. Consistent with this logic, the moderating effect is significantly more positive when technological distance is high: it is positive ($p = 0.067$) under high distance, and negative ($p = 0.055$) under low distance.

Overall, these tests strengthen our theoretical framework by providing evidence of the mechanisms through which broadband affects innovation. The pattern of results is consistent with our argument that pre-treatment co-invention strengthens the effect of broadband by helping overcome broadband's tacit knowledge limitations, while pre-treatment high ME span of control does so by reducing the likelihood that MEs encroach on R&D subsidiary activities.

4.4 Additional Analyses

4.4.1 R&D Expenditures and Resource Allocation

Our theoretical framework suggests that R&D subsidiaries' R&D expenditures may increase post-broadband because MEs may be more willing to fund R&D projects as their monitoring capabilities are enhanced, enabling easier detection and deterrence of agency problems like shirking or misrepresentation. We measure *Subsidiary R&D Expenditures* as the natural log of total R&D spending by the subsidiary. As shown in Appendix F Table F.1, R&D expenditures increase following broadband introduction, with larger and more statistically significant effects when time zone distance is low—consistent with improved monitoring being more feasible when synchronous communication is more feasible.

We find no evidence that this effect is moderated by *Pre-treatment High ME Span of Control*, which aligns with our theory. While span of control influences the likelihood that MEs assert tighter control post-broadband—a factor expected to shape innovation outcomes—it is less clear why it would affect MEs' willingness to allocate funding in the first place. We also do not observe moderation by *Pre-treatment Co-invention with ME*. Although pre-treatment co-invention may potentially enhance monitoring by increasing knowledge exchange, the pattern here—combined with the knowledge flow analyses in Section 4.3.2—suggests that co-invention may primarily operate by increasing the flow of knowledge from MEs to R&D subsidiaries. Overall, these results suggest that the moderating effects of co-invention and span of control are more consistent with changes in innovation productivity than changes in resource allocation.

4.4.2 Within-MNE Variation

To address potential confounds from for unobserved MNE-level factors—including their propensity to adopt broadband or prior investments in communication infrastructure—we estimate models with MNE-year fixed effects. This approach isolates within-MNE variation across subsidiaries within a given year. As shown in Appendix F Table F.2, the results remain consistent with our main findings, suggesting that unobserved MNE characteristics are not driving our results.

4.4.3 Alternative Innovation Outcome Measure

Finally, we examine whether broadband also improves *Innovation Market Value*, measured as the natural log of the market value of the patents filed within a given year. As shown in Appendix F Table F.3, broadband introduction has a significantly positive effect on *Innovation Market Value*. It remains positive regardless of time zone distance but is larger and more statistically robust when time zone distance is high—similar to the effect of broadband on *Innovation Quantity.* Also like *Innovation Quantity*, the moderating roles of *Pre-treatment Co-invention with ME* and *Pre-treatment High ME Span of Control* are more pronounced when the time zone distance is low. These results suggest that broadband not only increases the quantity but also the *quality* of innovation, further supporting our theoretical framework.

5. Discussion and Conclusion

CTs that reduce communication costs between MEs and R&D subsidiaries offer a potential solution to a central organizational challenge for MNEs: how to harness the potential benefits of geographically-distributed R&D despite the obstacles to innovation management imposed by geographic distance. As firms gain greater capacity for rich, high-quality communication with remote R&D subsidiaries, key aspects of innovation management like monitoring and sharing knowledge should become more feasible. Yet whether CT adoption actually improves R&D subsidiary innovation has remained theoretically and empirically unresolved due to two structural tensions. First, even the most advanced CTs fall short of in-person interaction as a means for transmitting tacit knowledge (Alavi and Leidner 2001, Srikanth and Puranam 2011, Forman and van Zeebroeck 2019), which is critical for both monitoring R&D effectively (Aghion et al. 2013, Glaeser et al. 2022) and sharing knowledge that is valuable to the innovation process (Allen 1977, Teece 1977, Berry 2015). Second, by reducing communication costs, CTs also make it more feasible for managers to intervene directly in R&D activities (Bloom et al. 2014), which can suppress the initiative and creativity needed for successful innovation (Amabile 1988, Holmstrom 1989, Aghion and Tirole 1997, Baker et al. 1999, Zhou 2003, Bernstein 2012). Therefore, we argue that whether CT adoption enhances innovation depends on organizational conditions that affect the extent to which (1) the impact of the CT's tacit knowledge transfer limitations on monitoring and knowledge-sharing can be mitigated, and (2) the CT's potential to enable managerial overreach can be constrained.

Specifically, we find that the extent to which R&D subsidiary innovation improves following a broadband-enabled reduction in the cost of communication with its ME varies significantly with (1) whether the ME and R&D subsidiary co-invented prior to broadband introduction, which helps overcome broadband's limitations in tacit knowledge transfer, and (2) whether the ME has a high span of control, which limits the likelihood of increased ME intervention. These findings persist through a battery of robustness tests, and additional analyses support the proposed mechanisms: the main effect of broadband is attributable to lower communication costs between ME and R&D subsidiary; prior co-invention amplifies the effect by mitigating tacit knowledge transfer limitations; and span of control amplifies the effect by constraining ME intervention. Most notably, the potential effect of broadband is greatest, and the moderating roles of span of control and prior co-invention most pronounced, when time zone distance is low, i.e., when improvements in synchronous communication are most feasible.

Together, these findings provide novel insight into the organizational conditions under which a CT-enabled reduction in communication costs enhances innovation, and they carry important implications for our understanding of CT adoption and the management of innovation in MNEs.

5.1 Contributions

First, we contribute to research on CTs and innovation by developing a contingency framework that explains when innovation improves after adopting a CT that reduces communication costs between management and R&D. Our framework addresses the ambiguity around the relationship between such CT adoption and R&D subsidiary innovation by theorizing two organizational conditions—prior co-invention with the ME and high ME span of control—that shape when CT adoption yields innovation gains. These conditions influence the extent to which a CT's tacit knowledge transfer constraints hinder improvements in monitoring and knowledge-sharing, and the likelihood that MEs use enhanced communication to tighten control. In doing so, we offer a more comprehensive view of CTs as tools for innovation management. This framework lays a foundation for future work on the impact of different types of CTs and the role of different organizational conditions both within and beyond the MNE context by anchoring such exploration in two core considerations: the impact of tacit knowledge transfer constraints on monitoring and knowledge sharing, and the potential for increased managerial control.

Second, our results inform efforts to understand longstanding heterogeneity in firm returns to investments in CTs (Schreyer 2000, Stiroh 2002, Van Ark et al. 2008, Bloom et al. 2012). This study goes beyond returns to overall firm productivity to examine returns to a specific firm activity that is critical to firm performance: innovation. By showing how organizational conditions shape whether and how CT adoption improves innovation outcomes, we reinforce the insight that adoption alone is insufficient to generate returns. Yet by integrating the potential for CT adoption to constrain innovation, we also challenge the oft-implicit assumption in this literature that because CT-enabled reductions in communication costs can decrease information asymmetries and facilitate knowledge flows, they are unambiguously beneficial (Garicano, 2000; Corrado and Hulten, 2010; Alfaro and Chen 2018). Our study suggests that heterogeneity in returns to CTs is attributable not just to variation in firms' ability to leverage the benefits of CTs but also variation in the ability to minimize negative consequences.

Third, we contribute to the MNE and global strategy literatures. While prior research has shown that MNEs often choose the locus of authority over R&D subsidiaries with the aim of minimizing geographic or expertise-based distance between management and R&D (Birkinshaw et al. 2006, Gumpert et al. 2022), our findings suggests that advances in CTs may reduce the salience of geographic proximity while heightening the importance of characteristics that mitigate the impact of a CT's tacit knowledge transfer constraints and potential for enabling managerial control. Our results also extend research on time zone differences in globally distributed MNEs (Espinosa and Carmel 2003, Cummings et al. 2009, Mell et al. 2021, Chauvin et al. 2024). While prior work has emphasized the coordination costs of time zone separation, our findings point to an underappreciated benefit: time zone differences can naturally constrain opportunities for excessive intervention by MEs. Methodologically, our approach demonstrates how transfer pricing reports can offer new opportunities for studying authority relationships within MNEs—a persistent challenge in global strategy research, especially with respect to R&D activities (Aghion et al. 2014). This enabled us to generate rare empirical insight into the internal authority relationships that govern R&D subsidiaries and the implications of CT-enabled reductions in communication costs. More broadly, it enables sharper identification of when and how organizational structure interacts with technology adoption to shape innovation outcomes.

Finally, our results have important practical implications for how MNEs manage geographically-dispersed R&D activities. Simply adopting CTs that reduce the cost of communication with management without considering organizational context may yield limited benefits for innovation. The results suggest MNEs may improve returns to CT adoption by encouraging collaborative relationships between MEs and R&D subsidiaries before adoption, or by assigning authority over R&D activities on the basis of ME characteristics like span of control or other features that can minimize the likelihood of tightened control. When practical constraints prevent optimizing ME-R&D subsidiary pairings on CT efficacy, MNEs might consider prioritizing technology investments in relationships with favorable conditions (e.g., prior co-invention or high ME span of control) or developing targeted interventions to improve conditions in high-priority relationships.

5.2 Boundary Conditions, Limitations, and Future Research

While our findings provide strong support for our proposed theoretical framework, several limitations suggest avenues for future research.

First, although broadband's staggered, exogenous rollout provides advantages for causal inference, it represents only one form of communication technology. Emerging tools like immersive telepresence, quantum communication, and AI-enhanced communication systems may differ in their ability to transmit tacit knowledge or facilitate real-time managerial intervention. However, such variation likely affects the *magnitude* rather than *direction* of effects, making our framework a valuable foundation for analyzing future technologies. In particular, it points to a potential tradeoff: as CTs become more effective at tacit knowledge transfer, which should benefit innovation, they may simultaneously become more powerful tools for control, which may constrain innovation. Future research may explore the implications this potential tradeoff holds for CT investment and organizational design.

Second, while our empirical setting offers a rare opportunity to assess the causal effect of CT-enabled reductions in communication costs between R&D subsidiaries and management—and how that effect depends on organizational conditions—we cannot directly observe changes in the frequency or content of communication between MEs and R&D subsidiaries. This reflects a critical tradeoff in our choice of empirical setting. Although we cannot evaluate fine-grained communication data, our setting does provide a credible source of exogenous variation in CT adoption both cross-sectionally and over time for a set of comparable R&D subsidiaries, along with rich variation in the moderating organizational conditions. The difficulty of identifying such a context is one of the main reasons why the literature examining the relationship between technology adoption and organizational design has remained limited despite its practical and theoretical importance (Eggers and Francis Park 2017).

To mitigate this limitation, we ground our framework in prior research documenting broadband's impact on communication (Ericsson et al. 2013, Bertschek et al. 2013) and the consequences of CTs and increased managerial communication through experimental studies, qualitative work, and cross-sectional surveys (e.g., Zhou 2003, Cummings et al. 2009, Bernstein 2012, Bloom et al. 2014). We conduct extensive analyses to isolate communication effects and assess whether the relationship between broadband and R&D subsidiary innovation behaves as our theoretical framework predicts. Nonetheless, future research that is able to directly observe changes in communication patterns across multiple organizations over time could yield even deeper insight into the dynamics we identify here.

Third, the organizational conditions that moderate the effect of CTs on R&D subsidiary innovation may themselves evolve over time, potentially as a direct result of the reduced communication costs. Prior research has shown that CTs can facilitate co-invention across locations, though primarily when actors are already technologically proximate (Rosenblat and Mobius 2004, Van Alstyne and Brynjolfsson 2005). CT adoption could also lead to changes in ME span of control, though the direction and magnitude of effects remains contested (Bloom et al., 2014). Examining when and how these moderating organizational conditions shift over time post-broadband is beyond the scope of the current paper but represents a promising avenue for future research.

Fourth, while our use of patent data provides a consistent and comparable measure of innovation across firms and time periods, patents capture only a subset of innovation activity. Future research could examine how CTs affect outcomes such as new product introductions, process innovations, or informal knowledge creation that may not be reflected in patenting behavior.

Finally, although our identification strategy leverages plausibly exogenous variation in broadband rollout and is supported by a range of robustness and placebo checks, we lack exogenous variation in prior co-invention and ME span of control. We mitigate this concern through a triple difference (DDD) research design and extensive supplemental analyses to rule out alternative explanations, but we interpret the moderating effects as consistent with, rather than definitive proof of, our theoretical framework.

Together, these limitations highlight the importance and difficulty of studying the relationship between communication technologies and organizational context. Our findings represent a meaningful step forward, offering a foundation for deeper exploration of how evolving CTs interact with organizational structure, inter-unit relationship history, and innovation processes.

5.3 Conclusion

This study advances our understanding of CTs as a tool for managing globally-distributed R&D. To our knowledge, we offer the first empirical evidence of whether and when adopting CTs that reduce communication costs between management and R&D subsidiaries improves R&D subsidiary innovation. By theorizing and empirically demonstrating that innovation gains depend on key organizational conditions—specifically, relationship history (prior co-invention by the ME and subsidiary) and organizational structure (the ME's span of control), we show how organizational context shapes not only the realization of potential benefits but also the mitigation of potential downsides. As new technologies continue to improve the speed and richness of communication across geographic distance, the interplay between organizational design and CTs will become increasingly central to managing global innovation. This study provides a foundation for future research at this intersection of communication technologies, organizational design, and innovation.

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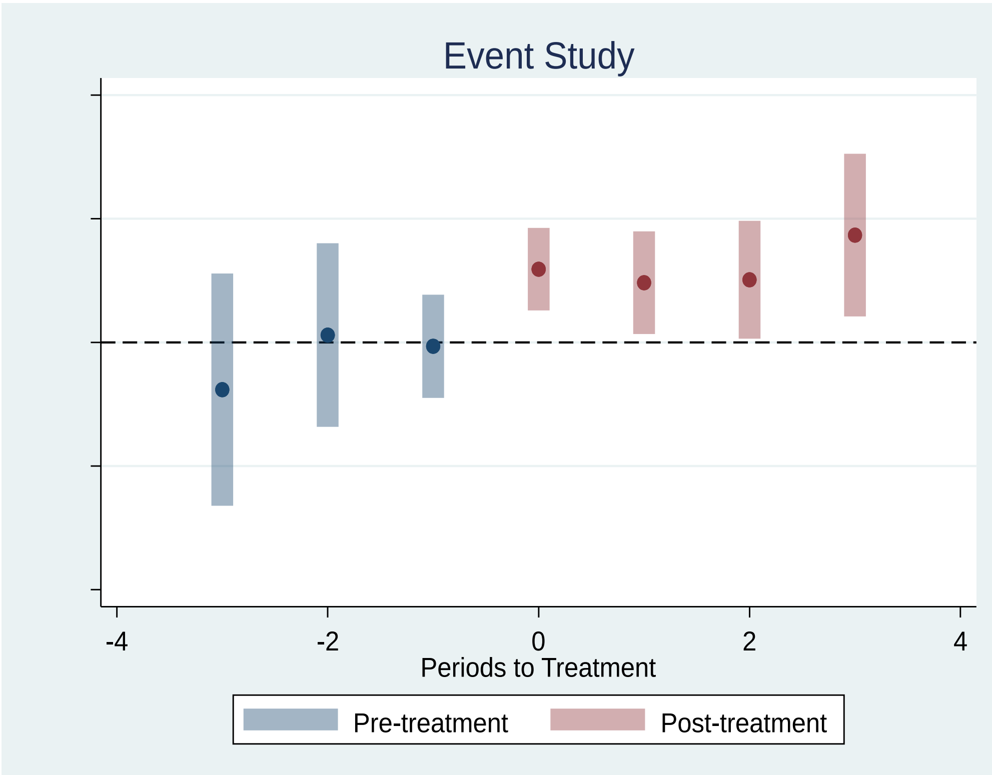
Figure 1:



Note: The x-axis is Periods to Treatment, where Treatment is coded as equal to one in the year after both the R&D subsidiary and managing entity reach the broadband penetration threshold. The y-axis is ATT, or the average treatment effect, which is the average change in innovation quantity one year later. This reflects the lag structure of our models. Therefore, the increase at t=0 is reflective of the change in innovation quantity two years after both R&D subsidiary and managing entity reached the broadband penetration threshold.

Table 1: Distribution of R&D Subsidiaries

Country	% of Total Subsidiaries	Broadband Introduction Year	Country	% of Total Subsidiaries	Broadband Introduction Year	Country	% of Total Subsidiaries	Broadband Introduction Year
Argentina	0.38%	2007	Greece	1.08%	2007	Portugal	0.68%	2004
Australia	2.23%	2004	Hong Kong	2.48%	2000	Romania	0.20%	2007
Austria	1.03%	2002	Hungary	0.68%	2005	Russian Federation	0.65%	2008
Belgium	1.98%	2002	India	2.00%	.	Singapore	1.50%	2002
Brazil	1.23%	2008	Indonesia	0.08%	.	Slovakia	0.05%	2006
Canada	3.13%	2001	Ireland	1.28%	2005	Slovenia	0.15%	2004
Chile	0.50%	2006	Israel	0.78%	2003	South Africa	0.63%	2015
China	3.00%	2008	Italy	2.95%	2004	South Korea	2.60%	2000
Colombia	0.33%	2010	Japan	3.20%	2002	Spain	1.43%	2003
Croatia	0.18%	2006	Luxembourg	0.03%	2004	Sweden	2.80%	2001
Czech Republic	0.70%	2005	Malaysia	0.45%	2009	Switzerland	1.93%	2002
Denmark	1.15%	2002	Mexico	1.28%	2008	Taiwan	1.55%	.
Ecuador	0.10%	2012	Netherlands	2.40%	2002	Thailand	0.63%	2011
Egypt	0.08%	.	New Zealand	0.63%	2005	Turkey	0.48%	2007
Estonia	0.30%	2003	Norway	1.05%	2003	United Kingdom	12.78%	2003
Finland	1.45%	2002	Peru	0.15%	2013	United States of America	21.21%	2002
France	5.58%	2003	Philippines	0.18%	.	Venezuela	0.10%	2010
Germany	5.50%	2003	Poland	1.20%	2006	Total	100.00%	

Note: This table contains the percentage of R&D subsidiaries in each country location. Broadband introduction year reflects the first year that the broadband penetration rate surpassed five percent market penetration rate in the country of the R&D subsidiary.

Table 2: Summary Statistics for R&D Subsidiaries

Panel A: Full Sample of R&D Subsidiaries

	Variable	Obs	Mean	Std. dev.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Innovation Quantity	3,999	0.41	0.83																	
2	Innovation Market Value	3,568	0.66	1.60	0.91																
3	Knowledge Flows from ME	3,999	0.08	0.38	0.40	0.38															
4	Post-Broadband Introduction	3,999	0.62	0.49	0.12	0.08	0.07														
5	ME Span of Control Pre-Treatment	3,822	14.62	11.31	-0.05	-0.05	0.04	-0.12													
6	Co-invention with ME Pre-Treatment	3,999	0.84	4.32	0.28	0.28	0.32	0.09	0.01												
7	ME Span of Control Knowledge Stock	3,999	154.64	263.52	0.30	0.25	0.12	0.16	0.24	0.17											
8	ME-R&D Subsidiary Time Zone Difference	3,819	4.49	4.46	-0.15	-0.11	-0.08	-0.15	0.04	-0.11	-0.13										
9	Technological Distance Pre-Treatment	3,999	0.20	0.33	0.20	0.20	0.03	0.06	-0.06	0.04	0.29	-0.03									
10	Global Connectiveness Pre-Treatment	2,879	0.89	1.13	-0.12	-0.10	-0.11	-0.39	0.03	-0.08	0.00	0.27	0.04								
11	ME-R&D Subsidiary Cultural Distance	3,597	11.40	9.59	-0.08	-0.08	-0.11	-0.18	0.08	-0.09	0.01	0.46	-0.01	0.49							
12	Host-Country Revealed Technological Advantage	3,999	0.86	0.53	0.21	0.20	0.10	0.23	-0.05	0.07	0.06	-0.19	0.07	-0.34	-0.24						
13	Host-Country Industry Market Concentration	3,755	0.48	0.07	-0.11	-0.14	-0.07	-0.05	0.05	-0.04	0.04	-0.05	-0.02	0.11	0.08	-0.14					
14	MNE Size	3,986	15.58	2.00	0.22	0.23	0.04	0.00	0.20	0.03	0.30	-0.13	0.13	0.01	-0.04	0.08	0.06				
15	MNE Diversification	3,999	0.65	0.56	0.13	0.11	0.01	-0.09	0.23	0.04	0.17	-0.07	0.07	0.02	-0.04	0.03	0.04	0.44			
16	MNE Stock Compensation Expense	3,999	7.53	5.28	0.09	0.16	0.03	0.13	0.16	-0.07	0.02	0.04	0.09	-0.02	-0.01	0.02	-0.02	0.24	-0.02		
17	R&D Subsidiary R&D Expense (ln)	3,999	1.51	1.79	0.05	0.05	0.02	0.04	-0.01	0.04	-0.05	-0.10	-0.01	-0.13	-0.13	0.10	-0.08	0.06	-0.01	0.11	
18	R&D Subsidiary Role	3,999	1.59	0.76	-0.05	-0.06	-0.03	0.01	-0.06	0.01	-0.02	0.02	-0.05	-0.02	-0.02	0.05	0.04	-0.18	-0.08	-0.13	0.30

Panel B: Sample of R&D Subsidiaries with only One Managing Entity (ME)

	Variable	Obs	Mean	Std. dev.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Innovation Quantity	2,609	0.22	0.56																	
2	Innovation Market Value	2,401	0.29	0.99	0.87																
3	Knowledge Flows from ME	2,609	0.05	0.29	0.42	0.36															
4	Post-Broadband Introduction	2,609	0.56	0.50	0.06	-0.02	0.05														
5	ME Span of Control Pre-Treatment	2,432	14.89	11.79	-0.08	-0.10	-0.05	-0.14													
6	Co-invention with ME Pre-Treatment	2,609	0.64	2.90	0.39	0.25	0.44	0.12	-0.03												
7	ME Span of Control Knowledge Stock	2,609	81.22	210.72	0.15	0.01	0.05	0.16	0.12	0.30											
8	ME-R&D Subsidiary Time Zone Difference	2,429	4.93	4.72	-0.12	-0.04	-0.02	-0.15	0.05	-0.08	-0.10										
9	Technological Distance Pre-Treatment	2,609	0.13	0.23	0.10	0.06	-0.02	0.01	-0.15	0.01	0.13	0.00									
10	Global Connectiveness Pre-Treatment	1,782	0.94	1.19	-0.06	-0.02	-0.06	-0.44	0.02	-0.06	-0.02	0.29	0.11								
11	ME-R&D Subsidiary Cultural Distance	2,320	11.25	10.02	-0.11	-0.08	-0.06	-0.22	0.13	-0.10	-0.03	0.49	0.07	0.51							
12	Host-Country Revealed Technological Advantage	2,609	0.84	0.56	0.08	0.07	0.05	0.17	-0.12	0.05	0.00	-0.20	-0.03	-0.33	-0.24						
13	Host-Country Industry Market Concentration	2,461	0.49	0.07	-0.11	-0.16	-0.07	-0.02	0.05	-0.06	0.08	-0.03	0.01	0.11	0.08	-0.08					
14	MNE Size	2,604	15.51	2.02	0.07	0.08	-0.02	-0.06	0.18	-0.01	0.24	-0.14	-0.03	0.02	-0.07	0.03	0.10				
15	MNE Diversification	2,609	0.68	0.59	0.01	-0.03	-0.04	-0.12	0.22	0.05	0.09	-0.13	-0.08	0.02	-0.09	-0.01	0.04	0.38			
16	MNE Stock Compensation Expense	2,609	7.82	4.93	0.05	0.10	0.04	0.12	0.26	-0.05	-0.04	0.10	-0.05	0.02	0.03	-0.08	0.08	0.21	-0.04		
17	R&D Subsidiary R&D Expense (ln)	2,609	1.58	1.87	0.00	-0.01	0.02	0.05	-0.01	0.05	-0.06	-0.11	-0.01	-0.11	-0.15	0.13	-0.12	0.07	-0.04	0.09	
18	R&D Subsidiary Role	2,609	1.55	0.73	-0.11	-0.14	-0.01	0.04	-0.18	0.03	-0.03	0.00	0.04	-0.09	-0.07	0.07	0.02	-0.16	-0.09	-0.02	0.28

Table 3: The Estimated Effect of Broadband Introduction on R&D Subsidiary Innovation Quantity

Dependent Variable: Innovation Quantity	Full Sample		Sample of R&D Subsidiaries with Only One Managing Entity				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post-Broadband Introduction	0.092	0.142	0.082	0.140	0.096	0.070	0.026
	(0.028)	(0.039)	(0.031)	(0.041)	(0.037)	(0.045)	(0.042)
	[0.001]	[0.000]	[0.008]	[0.001]	[0.009]	[0.119]	[0.545]
Pre-treatment Co-invention with ME * Post-Broadband Introduction					0.338		0.338
					(0.155)		(0.150)
					[0.030]		[0.025]
Pre-treatment High ME Span of Control * Post-Broadband Introduction						0.195	0.194
						(0.079)	(0.074)
						[0.013]	[0.009]
Control Variables	No	Yes	No	Yes	Yes	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pre-Treatment Global Connectiveness-Year Fixed Effects	No	Yes	No	Yes	Yes	Yes	Yes
Number of Observations	3999	2565	2609	1629	1629	1629	1629
Number of Clusters	945	618	688	435	435	435	435
R-squared	0.063	0.077	0.031	0.064	0.107	0.076	0.119

Note: Changes in sample size are due to missing control data. Pre-treatment Co-invention with ME and Pre-treatment High ME Span of Control are interacted with year fixed effects in columns 5 and 6, respectively, and in column 7. The main effects for Pre-treatment Co-invention with ME, Pre-treatment High ME Span of Control, and Pre-Treatment Global Connectiveness are absorbed by subsidiary fixed effects. All models are estimated using fixed effects OLS with robust standard errors clustered at the subsidiary level. Standard errors are in parentheses and p-values are in brackets.

Table 4: The Estimated Effect of Broadband Introduction on R&D Subsidiary Innovation Quantity by Time Zone

Dependent Variable: Innovation Quantity	Time Zone Difference							
	High				Low			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post-Broadband Introduction	0.165	0.112	0.090	0.046	0.141	0.074	0.046	-0.020
	(0.059)	(0.054)	(0.068)	(0.069)	(0.060)	(0.045)	(0.059)	(0.052)
	[0.006]	[0.040]	[0.183]	[0.508]	[0.019]	[0.098]	[0.436]	[0.699]
Pre-treatment Co-invention with ME * Post-Broadband Introduction		0.543		0.537		0.642		0.649
		(0.194)		(0.193)		(0.434)		(0.333)
		[0.006]		[0.006]		[0.141]		[0.052]
Pre-treatment High ME Span of Control * Post-Broadband Introduction			0.123	0.109			0.299	0.310
			(0.100)	(0.096)			(0.134)	(0.118)
			[0.222]	[0.256]			[0.027]	[0.009]
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pre-Treatment Global Connectiveness-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	800	800	800	800	829	829	829	829
Number of Clusters	194	194	194	194	241	241	241	241
R-squared	0.058	0.097	0.091	0.129	0.117	0.199	0.149	0.23

Note: Estimated on the sample of R&D subsidiaries with only one ME. Pre-treatment Co-invention with ME and Pre-treatment High ME Span of Control are interacted with year fixed effects in all columns. The main effects for Pre-treatment Co-invention with ME, Pre-treatment High ME Span of Control, and Pre-Treatment Global Connectiveness are absorbed by subsidiary fixed effects. All models are estimated using fixed effects OLS with robust standard errors clustered at the subsidiary level. Standard errors are in parentheses and p-values are in brackets.

Table 5: Exploring the Moderating Effect of Pre-treatment Co-invention with ME

Dependent Variable:	Knowledge Flows from ME						Innovation Quantity	
			High Time Zone Difference		Low Time Zone Difference		High Tech Distance	Low Tech Distance
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post-Broadband Introduction	0.029	-0.003	0.011	-0.014	0.048	0.009	0.223	-0.013
	(0.030)	(0.025)	(0.046)	(0.048)	(0.040)	(0.014)	(0.073)	(0.026)
	[0.335]	[0.910]	[0.808]	[0.775]	[0.234]	[0.516]	[0.002]	[0.624]
Pre-treatment Co-invention with ME * Post-Broadband Introduction		0.293		0.191		0.621	0.296	-0.304
		(0.164)		(0.109)		(0.229)	(0.161)	(0.158)
		[0.075]		[0.080]		[0.007]	[0.067]	[0.055]
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pre-Treatment Global Connectiveness-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	1629	1629	800	800	829	829	827	802
Number of Clusters	435	435	194	194	241	241	217	218
R-squared	0.024	0.119	0.018	0.097	0.053	0.226	0.139	0.301

Note: Estimated on the sample of R&D subsidiaries with only one ME. Changes in sample size are due to missing control data. Pre-treatment dummy variable of Co-invention with ME is interacted with year fixed effects in columns 2, 4, and 6-8. The main effects for the Pre-Treatment Co-invention with ME and Pre-Treatment Global Connectiveness are absorbed by subsidiary fixed effects. All models are estimated using fixed effects OLS with robust standard errors clustered at the subsidiary level. Standard errors are in parentheses and p-values are in brackets.