

Communication Technology and Innovation in Multinational Enterprises: The Role of Intra-firm Control Rights

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Abstract

We examine the effect of communication technologies on innovation within multinational enterprises (MNEs) by exploiting the staggered country-level introduction of broadband. We expect that the allocation of control rights within the firm will influence the benefits that MNEs realize from communication technologies. In particular, we theorize that because of the different responsibilities that headquarters and subsidiaries hold, the effect will depend on whether headquarters or another subsidiary controls the rights to the focal R&D subsidiary's innovation. We find that post-broadband introduction only subsidiary-controlled R&D exhibit significant improvements in the quantity, quality, and market value of patents. A battery of analyses examining patenting patterns and heterogeneity in MNE characteristics suggests that headquarters fails to fully leverage broadband to foster innovation in the R&D subsidiaries it controls because headquarters face greater demands for attention. We contribute by studying how intra-firm control rights affect knowledge creation and knowledge sharing within the firm. Our study highlights the importance of the delegation of control to understand the implications of technology on innovation and its market value.

Keywords: Control, innovation, property rights theory, communication technology, patents, multinational enterprises

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1. Introduction

Communication technologies play an integral role in managing geographically dispersed operations (Bloom et al., 2014; Garicano, 2000). They facilitate monitoring, transferring information, and coordination (Aghion et al., 2014). Consequently, such technologies enhance the ability of managers to efficiently and effectively control geographically distant subsidiaries and improve resource allocation decisions (Bloom et al., 2014; Dessein, 2002). In general, communication technologies are held as unambiguously positive for firm performance (see, e.g. Corrado and Hulten 2010). Nevertheless, little is understood about how the effects of communication technologies on firm performance vary based on who controls the activities.

We generate new insight into the conditions under which communication technologies improve firm performance by exploring how the realized effect might depend on whether headquarters or a subsidiary controls the activity.¹ Control rights is a fundamental topic in finance (Dass et al., 2013; Jensen, 1993; Jensen and Meckling, 1995; Lerner et al., 2003). The units with control rights are able to make strategic decisions, including selecting projects, allocating resources, and coordinating and monitoring activities (Aghion and Tirole, 1994; Grossman and Hart, 1986). We argue that the distinction between headquarters and subsidiaries is vital because they occupy different roles for the firm (Alfaro et al., 2018; Bolton and Scharfstein, 1998), raising the possibility of different abilities for exploiting communication technologies. On the one hand, unlike subsidiaries, headquarters are at the nexus of the corporate group. Therefore, its enhanced ability to communicate can provide better access to information and knowledge from across the group and alleviate information asymmetries for allocating financial resources to the subsidiaries they directly control (Bolton and Scharfstein, 1998; Stein, 1997). On the other hand, a growing literature in finance suggests that because attention is limited, top managers busy with many demands for their time realize lower performance than those less busy (Falato et al., 2014; Hauser, 2018; Lu et al., 2016). For

¹ This study focuses on the control of R&D subsidiary activities by other units (headquarters or another subsidiary). Such delegation is common within firms (Magelssen, 2020). Thus, we aim to provide insight into the benefits or costs of delegating control to an intermediate unit relative to headquarters control.

managers in headquarters, their responsibility for the firm's overall operations means that they face greater demands for attention than managers in subsidiaries (Bolton and Scharfstein, 1998; Williamson, 1985). As a result, managers in headquarters have limited attention that they can provide to each unit (Williamson, 1985). Consequently, headquarters as a unit may be less likely to devote as much attention as subsidiaries in leveraging communication technology to enhance performance in the units they control.

We focus on innovation as a measure of firm performance. We leverage new data on the market-adjusted MNE returns on the three-day window following the patent issue date to also consider the market value of the innovation (Kogan et al., 2017). Innovation is critical for firm growth and profitability but hard to control because of its inherent uncertainty, information asymmetries, and the difficulties of transferring tacit knowledge between organizational units (Aghion and Tirole, 1994; Robinson, 2008; Seru, 2014; Teece, 1977). The challenge is comparatively high for multinational enterprises (MNEs) whose research and development (R&D) activities are increasingly geographically dispersed across subsidiaries with diverse knowledge, expertise, and skills vital for innovation (Magelssen, 2020).

The literature on the management of innovation within firms, including the stream studying the role of centralization, predominantly views headquarters as the orchestrator that coordinates subsidiary R&D activities (Arora et al., 2014; Dellestrand and Kappen, 2012). Research has yet to study the role of subsidiaries that oversee MNE group innovation. This is a critical void because subsidiaries have become key managers of innovative activity worldwide by controlling the R&D rights and activities of other subsidiaries (Magelssen, 2020).

A dominant logic suggests that communication technologies facilitate innovation through the search for ideas, high-quality monitoring, and coordination for collaboration and knowledge sharing across MNE entities (subsidiaries and/or headquarters) (Alfaro and Chen, 2018; Forman and van Zeebroeck, 2019; Nonaka and Takeuchi, 1995; Sorenson et al., 2006; Teece, 1977). If headquarters is unable to provide as much attention to the R&D subsidiaries it controls as subsidiaries, we would expect that it will be less likely to leverage communication technologies for high-quality monitoring, sharing knowledge, and collaborating

for innovation. It may also be more likely than subsidiaries to rely on easier to employ financial metrics for selecting and monitoring R&D projects, which can stifle innovation outcomes (Manso, 2011) and make it less likely to select more novel, experimental innovation projects (Aghion et al., 2013; Hirshleifer et al., 1992; Holmstrom, 1989; Narayan, 1985). Consequently, headquarters-controlled R&D subsidiaries may realize fewer benefits from communication technologies than subsidiary-controlled ones.

This research faces two substantial challenges. First, control over activities within firms is notoriously difficult to observe (Aghion et al., 2014). Prior research has relied on proxies such as patent assignments that have legal confounders (Arora et al., 2014) and surveys whose evaluation is limited to cross-sectional estimates (Seru, 2014). Second, the delegation of control rights is endogenous to innovative behavior. Headquarters may choose to directly manage the most innovative subsidiaries, making it difficult to identify the effects of control rights on innovation.

We address these two challenges as follows. We start by using a unique dataset compiled from transfer-pricing reports from 78 MNEs that cover their 1,004 R&D subsidiaries worldwide from 1997 to 2011. Three features of this dataset allow us to document the innovation activities of these companies. First, transfer pricing reports specify the entities within the firm that hold control rights over the MNE's R&D activities and the entities that conduct R&D on their behalf (see, e.g., OECD, 2017, IRS Treas. Reg. §1.482). Second, each transfer pricing report includes information about the intra-firm activities for at least three years, allowing us to account for organizational and institutional changes that might affect innovation outcomes (e.g., OECD, 2017). Lastly, the information in the transfer pricing reports is strongly reliable (EY, 2013).²

To address the second challenge, we take the control rights as given and exploit exogenous variation in the ability to communicate with the staggered introduction of broadband technology at the country level. The rollout of communications infrastructure in a country has a significant impact on firm productivity

² Reporting this information is mandated by country governments, the reports are used in audits and court cases for both sides of the transaction (i.e., the MNE entity with control rights and the subsidiary executing innovation activities), and there are stiff penalties, and in some jurisdictions executives also face criminal charges, if the reports have incorrect information (EY, 2013).

(Roller and Waverman, 2001). Broadband technology, in particular, brought a radical improvement in the ability to communicate between locations. On the supply side, broadband infrastructure was costly for telecommunications companies to roll out (OECD, 2015). However, on the demand side, businesses rapidly adopted broadband once the infrastructure was in place because of its low adoption costs and the potential for substantial efficiency gains for businesses (Antonelli, 2002; Bertsek et al., 2013; OECD, 2015). These country-specific shocks allow us to estimate the effects of communication technology after firms have established intra-firm control rights.³ We merge these datasets with USPTO patent data based on inventor location and code subsidiary patent-based measures of innovation quantity, quality, collaboration, and knowledge flows and complement it with data on the market value of the patents.

We first employ a baseline difference-in-differences analysis to understand the overall effect of broadband on subsidiary innovation before applying a triple difference approach. The triple difference compares the change in the innovation of headquarters-controlled R&D subsidiaries after the introduction of broadband relative to headquarters-controlled without broadband at that time to the change in the innovation of subsidiary-controlled R&D subsidiaries after the introduction of broadband relative to subsidiary-controlled without broadband as the baseline counterfactual. Estimating the causal relationship of interest entailed finding a credible comparison. We construct a matched sample of headquarters- to subsidiary-controlled R&D subsidiaries using a vector of variables that include subsidiary industry and country and the mean pre-treatment values of subsidiary innovation quantity, market value, and scope, collaboration, knowledge flows, R&D expenditures, role, and MNE size, diversification, and stock compensation.

A key result emerges. We find that the introduction of broadband is associated with increases of 14.6 percent and 31.9 percent in patent quantity and market value, respectively, for subsidiary-controlled R&D.

³ Because changes in communication costs can lead to changes in the delegation of control within firms (Bloom et al., 2014; Dessein, 2002), we limit the sample to R&D relationships established before broadband introduction and exclude the observations that changed afterwards.

The effect of broadband on patent quantity and market value for headquarters-controlled R&D is, respectively, 15.6 and 31.5 percentage points smaller. The data show that these results are not simply driven by subsidiary-controlled R&D subsidiaries catching up to headquarters-controlled ones. These findings imply that the realized effect of communication technologies depends on how firms delegate control over activities. Aligned with our initial prediction, the results suggest that headquarters are less effective at leveraging the full potential of broadband technology for overseeing R&D activities.

We investigate the mechanisms underpinning these results. Of note, we do not find evidence that changes in R&D funding, the centralization of control rights, or changes in the number of patents solely invented by the focal subsidiary explain the results. In contrast, we find that a key channel through which innovation increases is through an increase in collaborative innovations. Post-broadband, subsidiary-controlled R&D subsidiaries experienced a significantly larger increase in patents co-invented with their controlling subsidiary than headquarters-controlled ones. Similarly, we analyze knowledge flows, proxied by the number of backward citations to the controlling entity, and find evidence of a larger increase in communication after the introduction of broadband between subsidiaries and the R&D subsidiaries they control than for headquarters. Broadband facilitates high-quality monitoring that motivates R&D subsidiaries to seek and integrate a greater scope of novel knowledge in innovations. We find that subsidiary-controlled R&D subsidiaries had a larger increase in innovation scope than headquarters-controlled. We observe this result with the proportion of new citations to prior art (Katila and Ahuja, 2002).

Finally, consistent with the argument of headquarters having greater demands for attention, we find that the effects rise in MNE size, diversification, and when headquarters must invest more effort to control activities such as when the R&D subsidiary is in a country that is culturally very different or has a different official language. Aligned with studies that show that management focuses on areas of expertise and overlooks areas distant from their expertise when their attention is limited (Lo et al., 2021), we find that the effect is most salient when the R&D subsidiary is technologically distant from the control entity. Post-broadband, headquarters-controlled R&D have a significantly smaller change in innovation than subsidiary-

controlled when the controlling entity (headquarters or subsidiary) is technologically distant from the R&D subsidiary. Altogether the results suggest that when headquarters have greater demands for attention, it undermines the marginal value of communication technology on knowledge generation and sharing.

In summary, subsidiaries with control rights were more effective in leveraging broadband to coordinate collaboration, transfer knowledge, and motivate exploration that fosters innovation and greater market value than headquarters. This result aligns with our argument that functional differences between MNE entities affect their exploitation of communication technologies.

2. The Role of Broadband on Innovation

Broadband was one of the most critical technological changes for business organizations. It replaced phone line technology and allowed video conferencing, two-way communication, and faster data transfer. With broadband technology, the same network system provides voice, video, and data transfer, essential for streaming videos and teleconferencing (OECD, 2015).

Broadband can affect innovation through several mechanisms. First, it facilitates the transfer of tacit knowledge and soft information between a controlling entity and an R&D subsidiary regarding the progress of a given R&D effort and its prospects. Tacit knowledge cannot be communicated through the written or spoken word but is transferred through observation and demonstration (Polanyi, 1966). Video conferencing makes the transfer of tacit knowledge more feasible (Forman and van Zeebroeck, 2019; Nonaka and Takeuchi, 1995; Sorenson et al., 2006). It also facilitates relationships for obtaining soft information. Innovation activities generate noisy signals regarding their progress and prospects, but an R&D subsidiary will accumulate “soft” information about them (Scherer, 1999; Seru, 2014). If this information is difficult to transfer to the controlling entity, then the R&D subsidiary has the opportunity to exploit the information asymmetry for their own interests, such as championing or continuing projects that should be ended in order to secure resources (Robinson, 2008; Seru, 2014). To circumvent this possibility, controlling entities avoid approving and funding projects for which progress and prospects are more challenging to communicate (Robinson, 2008; Seru, 2014). In turn, R&D subsidiaries avoid proposing such projects in the first place

(Rotemberg et al., 1994; Seru, 2014).

By improving the transfer of tacit knowledge and soft information, broadband technology can increase the number of R&D projects that are proposed, approved, and funded. While innovations that emerge from novel projects tend to be of higher value (Hall et al., 2005), they are associated with greater uncertainty that makes assessing and communicating progress and prospects especially difficult (Rotemberg et al., 1994; Seru, 2014). Thus, the richness of communication that broadband enables may lead to more novel projects.

Second, communication technology makes it easier for the controlling entity to provide high-quality monitoring. High-quality monitoring enables the transfer of soft information about the progress and prospect of R&D projects, provides timely and quality feedback, and develops inter-unit relationships. R&D subsidiaries must be motivated to actively seek, propose projects, and integrate new knowledge for innovation and will generally avoid exploration if the controlling entity does not provide high quality monitoring. High quality, interim feedback both assure the R&D subsidiary of higher-quality performance evaluation based more on an assessment of its effort than simply the outcome of whether a particular project is successful and also provides useful guidance from the controlling entity that likely has better information about the commercial or product market prospects of an R&D project (Manso, 2011). Such efforts can increase the motivation of those in the R&D subsidiary to seek new knowledge and propose and pursue more novel, exploratory projects (Manso, 2011; Robinson, 2008; Rotemberg et al., 1994; Seru, 2014) as well as the controlling entity's likelihood of approving such exploratory projects (Azoulay et al., 2011; Manso, 2011). To the extent that the controlling entities use broadband to enhance the quality of monitoring, we would expect the R&D subsidiaries they manage to integrate more new knowledge.

Third, broadband makes it easier for R&D subsidiaries to collaborate and share knowledge with entities both inside and outside the firm. Communication technologies facilitate knowledge-sharing and innovation across geographic distance (e.g., Agrawal and Goldfarb, 2008; Ding et al., 2010; Forman and van Zeebroeck, 2019; Forman and Van Zeebroeck, 2012). In turn, knowledge-sharing and collaboration lead to more novel, higher quality innovations in multi-unit firms (Singh, 2008). Controlling entities may amplify

this opportunity by brokering and coordinating collaboration and knowledge sharing (Fleming et al., 2007).

Nevertheless, broadband is a shock to the amount of information available for the controlling entity. This shock should be particularly salient for headquarters because of its responsibilities for the MNE group. As explained below, we expect that the extent to which controlling entities effectively utilize broadband to foster innovation differs based on whether the entity functions as the headquarters or a subsidiary.

3. Control Rights

Control rights are the rights to make strategic decisions regarding the development, use, extension, modification, and termination of assets (Grossman and Hart, 1986; Hart and Moore, 1990). A small growing body of research uses property rights theory to understand the delegation of control rights within firms (Aghion et al., 2014; Aghion and Tirole, 1997; Hart and Moore, 1999).⁴ Work in this stream generally focuses on predicting when control rights will be centralized versus decentralized (Bloom et al., 2018, 2014; Garicano, 2000). Substantially less is known about the effects of control rights on value creation within firms (Aghion et al., 2014; Magelssen, 2020). This is important because the control entity can have a significant impact on the types of innovations created. Using a coal mine and coal plant as an example, Grossman and Hart (1986) demonstrate that the entity that holds control rights will determine which innovations are made to it. Because the MNE entities with control rights approve, fund, direct, and monitor the activities of the R&D subsidiaries they control (see, e.g., Appendices I and II), their characteristics are likely to influence value creation within firms.

⁴ Our study focuses on formal authority within firms. Real authority is about where information resides within the firm. Communication technologies reduce the friction of transferring information to the entity holding formal authority within the firm (Dessein, 2002). Therefore, one might expect that it would shift real authority away from the R&D subsidiaries to the controlling entity (Bloom et al., 2014; Garicano, 2000). We assume that since both headquarters and subsidiaries capitalize on the innovations created by the R&D subsidiaries that they control, they will be similarly motivated to alter the real authority in R&D subsidiaries. One might expect, however, that because the headquarters is controlled by the board of directors and is more proximate to shareholders, headquarters might face stronger pressure to yield MNE fiscal performance. In such a case, headquarters would have a greater tendency to reduce the real authority of R&D subsidiaries, which would lead to a greater reduction in motivation for headquarters- than subsidiary-controlled ones (Aghion and Tirole, 1997). This prediction goes in the same direction as that based on limited attention and is consistent with our findings for innovation scope.

Both headquarters and subsidiaries have incentives to foster innovation in the R&D subsidiaries that they control. The MNE entities with control rights hold income rights to any intellectual property created (see, e.g., OECD, 2017; IRS Treas. Reg. §1.482). They may accrue substantial income from blockbuster innovations or bear the losses from the failed innovative efforts of their controlled R&D subsidiaries (Magelssen, 2020). Governments uphold subsidiary rights and impose substantial adjustment costs to MNEs for revoking their rights.⁵ Consequently, intra-firm control rights are credible and motivate MNE entities to create value (Magelssen, 2020; Magelssen et al., 2022). Thus, we assume that both headquarters and subsidiaries will want to maximize value creation in the subsidiaries they control.

A primary difference between headquarters and subsidiaries is that it has the additional responsibility for overall MNE operations. Research on headquarter-subsidiary relationships has long held that connections with headquarters are important (Oxley and Pandher, 2016). Since headquarters is at the center of MNE operations, it can provide enhanced information and insight into innovation opportunities (Ambos and Birkinshaw, 2010). Moreover, direct control by headquarters provides greater motivation due to the possibility of career advancement and greater access to resources if the subsidiary performs well (Knott and Turner, 2019). Communication and positive attention from the headquarters increase subsidiary initiative. Ghoshal and Bartlett (1988) find that high levels of headquarter-subsidiary communications (compared to low-levels) are positively associated with subsidiary creation, adoption, and diffusion of innovations.

On the other hand, responsibility for overall firm performance and operations may lead to busy managers at headquarters, with high demands on the amount of information they must process (Williamson, 1985). Managers are bounded in their cognitive capacity, and top management attention is scarce (Simon,

⁵ Governments require that the subsidiaries with control rights receive the appropriate residual income from the innovations they control, and require MNEs to compensate MNE controlling entities with the net present value of any of their controlled innovations transferred to another entity within the firm (OECD, 2017). Governments have a vested interest in ensuring that subsidiaries receive their appropriate income because they receive the tax revenues on the profits of subsidiaries in their jurisdictions. Internal transfers of innovation control rights are flagged for audits and receive substantial penalties if the controlling entity is not adequately compensated (EY, 2013). In interviews with managers and experts, interviewees stated that internal transfers of control rights over intellectual property often can cost in the hundreds of millions to multiple billions of dollars, making it prohibitively costly to internally transfer.

1996, 1951). The greater the operations under the control of headquarters, the less attention they can invest in the units they control (Hart and Moore, 1999). Transferring information requires effort (Aghion et al., 2014). Attention constraints may preclude headquarters from exerting the effort necessary to leverage communication technologies for soft information, high-quality monitoring, coordinating collaboration, and sharing knowledge to foster innovation. Busy top managers may revert to heuristics and quantitative metrics to assess projects and outcomes that require less effort in communication. Yet, reliance on such metrics reduces innovation outcomes (Manso, 2011).

We do not suggest that the headquarters is necessarily less capable than subsidiaries in managing R&D activities. Instead, we argue that because headquarters have more constraints on their time and attention than the typical subsidiary, they are less likely to invest the effort to use communication technologies to foster innovation. This implies that the difference in the effect of broadband on innovation between headquarters- and subsidiary-controlled R&D subsidiaries will be more pronounced when headquarters has more constraints on its time and attention.

4. Data and Sample

We compile a novel dataset using confidential data from transfer pricing reports from a set of 78 MNEs.⁶ We merge these data with data from a variety of different sources: The World Bank World Development Indicators (WDI), the United States Patent and Trademark Office (USPTO), the extended database on the economic value of patents from Kogan et al. (2017), the OECD online database, the Bureau van Dijk's Orbis database; and the International Country Risk Guide. Our data cover the years 1997-2011.

4.1. Broadband Technology Data

Over the sample period, broadband technology was introduced in countries at varying points in time. The staggered introduction alleviates some concerns over institutional factors driving the analyses results. Given the significant economic and social impact of broadband technologies, governments worldwide

⁶ Data was obtained under confidentiality agreements.

created agendas to stimulate broadband deployment within their countries (OECD, 2015). For instance, the European Commission adopted a digital plan to have 100 percent broadband connection coverage by 2013 in every E.U. country (OECD, 2015). Early adopting countries include Hong Kong, South Korea, Canada, and Sweden; late adopting countries include Columbia, Venezuela, and South Africa. By 2011, most countries in our sample had introduced broadband technology. Once introduced, the technology diffused rapidly across businesses (OECD, 2015).

We obtain data on fixed broadband subscriptions from the WDI. The data contains the percentage of fixed broadband subscriptions in the population (both businesses and residences) and represents the market penetration of broadband technologies. Fixed broadband subscriptions are accounts, irrespective of payment method, that provide high-speed (equal to or greater than 256 kbit/s) access to public internet TCP/IP connection in fixed locations.⁷ Broadband technologies include a cable modem, digital subscriber line (DSL), fiber optic, satellite, fixed wireless, broadband over power lines (BPL).

The availability of communication infrastructure can significantly influence the productivity of firms in a region, even at relatively low penetration rates (Roller and Waverman, 2001). We use a five percent broadband penetration rate as the threshold for the introduction of broadband technology. Since communication technologies function best when both parties have access (Forman and van Zeebroeck, 2019), we code *Post-Broadband* as a binary indicator set equal to one in the year after the penetration rate reaches five percent for both the controlling entity and the R&D subsidiary location. Early broadband introduction typically occurs in industrial or city centers where MNEs locate, and MNEs tend to adopt communication technologies once they are available (Antonelli, 2002; OECD, 2015). The mean and median length of time for broadband technology market penetration to go from no broadband technology to a five percent market penetration is two years. We test the sensitivity of the analysis to different market penetration thresholds in Section 6.4.

⁷ (<https://data.worldbank.org/indicator/IT.NET.BBND>).

4.2. Data on Intra-firm Relationships

We collect information on MNE entities with control rights over the R&D activities, subsidiary R&D activities, and R&D expenses from the transfer pricing reports. Governments require that MNE entities receive the appropriate financial income for their activities and their rights to MNE assets and therefore mandate that MNEs document them in transfer pricing reports (see, e.g., OECD, 2017, IRS Treas. Reg. §1.482). The reports record control rights based on information from written contracts between MNE entities (see, e.g., contract clauses in Appendix A from a contract in an appendix of a transfer pricing report), payment and transaction flows, and interviews with management. The transfer pricing reports specify the MNE entities with control rights over innovations and which entities perform R&D under their control.

We code separate binary indicators *Headquarters-Controlled* and *Subsidiary-Controlled* R&D based on the descriptions contained in the reports. Specifically, we define subsidiary B as controlled by subsidiary A at time t if at time t subsidiary B is documented in a transfer pricing report as contracted or performing R&D activities on behalf of subsidiary A or being under the direction or control of subsidiary A. We follow the same procedure for the headquarters. Appendix B contains a redacted sample from a randomly pulled transfer pricing report. In the Appendix example, Subsidiary A was coded as a subsidiary with control rights and Subsidiary B was coded as an R&D subsidiary performing R&D under the control of Subsidiary A.

Our study concentrates on the effects of communication technology and control rights on subsidiary innovation rather than why MNEs decide to conduct R&D in particular locations. Therefore, our analysis is conditional on the MNE assigning R&D activities to the subsidiary. We start with the sample of 1,004 subsidiaries that performed R&D on behalf of another MNE entity over the sample period of 1997 to 2011, accounting for 4,395 subsidiary-year observations. Although the MNEs operate in a variety of industries, the majority operate in manufacturing industries.⁸ In comparing the MNEs in the sample to existing research, the proportion of total foreign subsidiaries that perform R&D (16.9 percent compared with 18.2

⁸ 78 percent of the MNEs are headquartered in North America, 19 percent in Europe, and the remainder in Asia.

percent) and the average number of total MNE patents produced per year (16.10 compared with 18.65, $p < 0.29$) are similar to Berry (2014).

There are 96 R&D subsidiaries that had a change in control over their R&D activities over the sample window, 79 of which occurred in or after the year of broadband introduction. To ensure changes in control rights do not drive the results, we exclude from the sample observations whose control rights changed in or after the year of broadband introduction. This reduced the sample by 155 observations to a sample of 4,240 subsidiary-year observations on 997 subsidiaries. Four of the subsidiaries in the sample licensed technologies from another MNE entity. We removed the four subsidiaries from our sample to avoid conflating the effects of intra-firm control with licensing relationships.⁹ Finally, we exclude control relationships with pure tax havens in this study since these structures are set up for tax purposes.¹⁰ Eliminating control relationships with pure tax havens reduced the sample to 946 subsidiaries. The final sample includes 4,009 subsidiary-year observations for 946 controlled R&D subsidiaries over 1997-2011.

4.3. Data on Innovation Outcomes

Patent data on inventor locations, assignees, forward and backward citations, and patent technological classes were gathered from the United States Patent and Trademark Office website (www.uspto.gov).¹¹ Data was collected on all granted patents assigned to each MNE or any subsidiary within the MNE group. For each MNE and its subsidiaries, we searched the USPTO database for patents assigned to the MNE or any of its subsidiaries based on the full legal entity name and variations of the legal entity name based on the legal root name, including variations such as “Inc.”, “Inc”, “Corporation”, “Incorporation”, “AG”,

⁹ The relationship between licensee and licensor is distinct as licensors typically have greater strategic discretion than an R&D subsidiary controlled by another MNE entity. Including these four subsidiaries do not alter the results.

¹⁰ The pure tax haven has no physical operations and limited employees. It receives income from the innovations, and the headquarters tend to exert control by making strategic decisions over those R&D subsidiaries.

¹¹ A limitation is that we rely on USPTO data, not global patent data. However, it is common practice to use patent data from one patent authority due to differences in the data from different patent offices (Jaffe and Trajtenberg, 2002). While the USPTO data can have a bias towards U.S. MNEs and U.S. subsidiaries, firms active in the U.S. have a strong incentive to file for intellectual property protection in the U.S. As the majority of MNEs in the sample are headquartered in the U.S., and all MNEs in the dataset have at least one location in the United States, the bias should be somewhat alleviated by all MNEs in the sample having an incentive to patent their innovations with the USPTO.

“SAS”, “SAS”, etc. For cases where there was ambiguity over whether the patent was associated with a particular MNE, we examined whether the assignee location matched one of the MNE’s locations. This led to 50,934 patents assigned to the MNEs in the dataset.

We downloaded the complete patent data from the USPTO website.¹² Each patent filing contains information on the inventor and the inventor’s location (country, state, and city). We manually matched the MNE entities in the dataset to their invented patent(s) based on the inventor city, state, and country and to the year based on the patent filing date since the filing date is closer to the invention of the patent than the patent grant date. For cases with multiple R&D entities in the same city, we matched the patent based on the overlap in the assignee name and the MNE entity name. If the MNE entity has similar root names, then we matched based on the technological focus of the entity (e.g. two pharmaceutical subsidiaries performing R&D on drugs, the patent is associated with an oncological drug, then the patent would be associated with the subsidiary doing oncological research rather than the subsidiary doing blood treatment research). There were 29,028 patents with only one inventor, and 10,711 had multiple inventors from the same MNE entity location and thus were coded to one entity. The remaining 11,195 patents had inventors from multiple MNE entity locations and were therefore coded to multiple entities. For the private economic value of patents, we merged by patent number the extended dataset on patent value from Kogan et al. (2017).¹³

4.3.1. Measuring innovation outcomes

Patents are an externally validated indicator of technological novelty commonly used in the finance literature to explore firm innovation (Griliches, 1990; Lerner and Seru, 2017). We measure *Innovation Quantity* as the total number of successful patent applications associated with the subsidiary’s inventors each year. We measure *Innovation Quality* as the number of prior art citations (“forward citations”) that a patent receives from other firms (excluding examiner citations) within five years of a patent’s file year.

¹² Patent data was downloaded using the algorithms from <https://www.leydesdorff.net/indicators/>.

¹³ The extended database to 2020 was accessed on October 12, 2021 at: <https://github.com/KPSS2017/Technological-Innovation-Resource-Allocation-and-Growth-Extended-Data>.

Forward citations are highly correlated with an innovation's underlying value and importance (Hall et al., 2005; Lanjouw and Schankerman, 2004). We take the natural log plus one of the values of innovation quantity and innovation quality for the analyses. Whereas innovation quality represents the scientific value of a patent, we use *Innovation Market Value* for the private economic value of a patent. For this, we employ the real value of each patent constructed by Kogan et al. (2017). The measure is the natural log of the total market-adjusted MNE returns in millions of dollars on the three-day window following the patent issue date for the patents invented by the focal R&D subsidiary in that year, deflated to 1982 using the CPI (for details, see Kogan et al., 2017). It represents the expectation of private value from the innovation and has been shown to provide additional insights into the relative importance of patents (Kogan et al., 2017).

Lerner and Seru (2017) detail a set of critical challenges that patent data poses in the finance literature relevant to our analysis. The first is truncation. Because there is a gap between application and grant dates, there is a mechanical tail-off in the number of patents granted in the years near the end of a patent database. The average patent is granted within 23 months of filing (USPTO, 2021). The truncation issue is also relevant to correctly measuring forward citations, as older patents have more opportunities to be cited. To minimize this issue, we measure *Innovation Quantity* using only patents filed until three years before the last year in the USPTO database at the time of collection. Second, we only include forward citations made within the first five years of a patent's file year so that each patent has the same number of years to receive citations and restrict the sample used for the estimations of *Innovation Quality* to patents filed by 2009. A caveat is that we do not capture patents whose impact takes longer to emerge. Nonetheless, this measure captures patents that are likely to be relatively economically valuable (Hall et al., 2005; Lanjouw and Schankerman, 2004), and we interpret the results for *Innovation Quality* with caution.

Lerner and Seru (2017) also explain that patent filing and patent citation patterns can vary by technology class and region, both of which are relevant to us. We take steps to address this by using a triple difference estimation approach which compares changes rather than levels of patenting and by using a matched sample that compares geographically and technologically similar firms. We also observe the effect of broadband

on patenting in multiple time periods due to its staggered introduction.

Finally, we follow Balsmeier et al. (2017) in analyzing a suite of patent-based measures of innovation. We measure *Co-invented Patents* as the number of patents in a given year for which the inventors listed on the patent are in different MNE locations. *Co-invented Patents with Control Entity* are the total number of patents in a given year that have inventors listed from both the subsidiary and the control entity locations. *Sole-invented Patents* is the number of patents for which the listed inventors are from one MNE location. These variables provide insight into how the R&D subsidiary's approach to innovation becomes more or less collaborative (Forman and van Zeebroeck, 2019; Forman and Van Zeebroeck, 2012). We measure *Knowledge Flows* as the total number of backward citations to the controlling entity across an R&D subsidiary's patents in a given year that the subsidiary did not previously cite in the last five years (excluding examiner citations). Increases in this variable after the introduction of broadband would be consistent with the controlling entity transferring more knowledge to the R&D subsidiary (Sorenson et al., 2006). We take the natural log plus one of co-invented patents, sole-invented patents, and knowledge flows. Finally, we measure *Innovation Scope* as the proportion of citations to prior art (excluding examiner citations) in the focal year that were neither previously cited by the subsidiary in the last five years nor developed by the subsidiary. Innovation scope measures the extent to which an R&D subsidiary's search process became more or less exploratory (Katila and Ahuja, 2002).

4.4. Other Financial Data

We also collected information on host-country, industry, and MNE-level factors that can influence subsidiary innovation from several sources. The *Revealed Technological Advantage (RTA)* index from the OECD was used for each country-industry's technological specialization. Local competition can influence subsidiary innovation and knowledge flows. Using global historical data from the Global Vantage database, we construct the host country-industry *Market Concentration Index*, operationalized as the sum of the proportion of total revenues earned by the four largest firms in the host country-industry location. We rely

on Bureau van Dijk for data on *MNE Size*, measured as the natural log of MNE revenues, *MNE Stock Compensation*, measured as the natural log of total MNE stock compensation expense each year (Oxley and Pandher, 2016),¹⁴ and *MNE Diversification* calculated using the entropy measure of diversification based on the MNE's share of total sales in each business segment (see Palepu, 1985).

An increase in the ability to communicate can provide access to funding and affect the activities assigned to a subsidiary. Therefore, we employ subsidiary fixed effects and only enter R&D and subsidiary role as secondary analyses. Subsidiary R&D is the natural log of the subsidiary's total R&D expenditures. Subsidiaries that perform more activities may have more innovation. Subsidiary Role is a count for the number of activities (R&D, manufacturing, distribution, and service) the subsidiary performs. We control for subsidiary industry using the two-digit Standard Industrial Classification (SIC) code fixed effects and time using year-fixed effects. All independent variables are lagged by one year.

4.5. Descriptive Statistics

Table C.1 in Appendix C shows the distribution of the sample of R&D subsidiaries across country locations by control entity type. The R&D subsidiaries are dispersed across country locations with the greatest percentages in the United Kingdom and the United States. The years of broadband introduction range from 2000 to 2015, with 2004 as the median year of broadband introduction for the sample.

Table 1 contains the mean values of the variables of interest by the type of entity holding control rights to the R&D subsidiary's innovation activities. Approximately 53.0 percent of the R&D subsidiaries performed activities under the headquarters' control, and 70.1 percent were under the control of a subsidiary. Some R&D subsidiaries have several different MNE entities that control their different R&D projects. Therefore, the table reports summary statistics for those R&D subsidiaries whose innovation activities are controlled by the headquarters only, those that are controlled by a subsidiary only, and those

¹⁴ Stock compensation can affect incentives to innovate (Oxley and Pandher, 2016). We rely on MNE total stock compensation because subsidiary-level stock compensation data and managerial incentive data were unavailable.

that have both subsidiary(ies) and headquarters control their R&D. Panels A and B in Table 1 show the mean values pre- and post- broadband introduction, respectively. Panel A in Table 1 shows that the mean value of innovation quantity is relatively similar for headquarters- and subsidiary-controlled pre-broadband introduction. Whereas innovation quality is slightly higher for headquarters-controlled R&D, innovation market value is slightly higher for subsidiary-controlled R&D. In Panel B, we find that subsidiary-controlled R&D have unambiguously greater average innovation outcomes than headquarters-controlled. Post-broadband introduction, subsidiary-controlled had a non-logged average of 1.76 patents compared with a non-logged average of 1.35 patents for headquarters-controlled R&D subsidiaries. The average total market value of patents produced by subsidiary-controlled R&D units was \$2.55 million post-broadband, compared to \$1.52 million for headquarters-controlled.

-----Insert Table 1 Here -----

5. Empirical Strategy

5.1 Difference-in-Differences

To understand the baseline relationship, we begin by analyzing the impact of the introduction of broadband on R&D subsidiary innovation using the model in Eq. (1) below:

$$Y_{i,t} = \beta_1 Post\ BroadBand_{ct} + \beta_2 X_{ijt} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (1)$$

Where $Y_{i,t}$ refers to the dependent variable of interest of subsidiary i in year t . $Post-Broadband_{ct}$ is a variable that equals one after broadband has been introduced. X includes time-variant country-industry, MNE, and subsidiary controls. We control for time-invariant subsidiary factors represented by α_i with subsidiary fixed effects. We also incorporate a full set of year dummies, represented by γ_t to control for factors that might affect innovation output in any given year. The error term is ε_{it} .

5.2 Triple-Difference

We use a triple difference approach to compare the innovation output of R&D subsidiaries that are headquarters- versus subsidiary-controlled before and after broadband introduction. For these analyses, $Post-Broadband$ is set equal to one in years after broadband technology has been introduced. The reference

group are those subsidiaries (by controlling entity type – headquarters versus subsidiary) located in countries and/or with controlling MNE entities in countries that do not have broadband technology at that time. The triple difference estimation addresses the endogeneity of control rights by accounting for the underlying difference in innovation output for each type of relationship. We estimate the following:

$$Y_{i,t} = \beta_1 \text{Controlled by Parent} * \text{Post BroadBand}_{i,j,t} + \beta_2 \text{Post BroadBand}_{i,j,t} + \beta_3 X_{ijt} + \alpha_i + \eta_{it} + \gamma_t + \varepsilon_{it} \quad (2)$$

β_1 is the coefficient of interest. It reflects the differential innovation performance of headquarters- relative to subsidiary-controlled R&D subsidiaries in treated areas after the change, using the difference between headquarters- and subsidiary-controlled R&D subsidiaries in untreated areas as the baseline counterfactual. β_2 captures the change in innovation outcomes for subsidiary-controlled R&D subsidiaries in countries with broadband introduction relative to subsidiary-controlled R&D subsidiaries without broadband at that point in time. We incorporate interactions of headquarters-controlled and year fixed effects to isolate the triple differences η_{it} (Pischke, 2005). The main effect for the binary indicator of headquarters controlled is absorbed by subsidiary fixed effects. Standard errors are clustered at the subsidiary level (dyadic level) for the subsidiary-level (dyadic) analysis to adjust for heteroscedasticity and within-subsidiary (within-dyadic) correlation over time.

5.3 Matched Sample Analysis

There might be systemic differences in the capabilities or quality of headquarters- versus subsidiary-controlled R&D subsidiaries that can affect the change in innovation with access to communication technology. We construct a propensity score matched sample to control for differences. We matched headquarters- to subsidiary-controlled R&D subsidiaries based on the same industry and country, and the pre-treatment mean value of subsidiary innovation quantity, market value, scope, collaboration, knowledge flows, R&D expenditures, and role, and MNE pre-treatment mean size, diversification, and stock compensation. We used nearest neighbor matching without replacement. The balancing tests indicated that the variables were balanced after matching (see Table C.2 in Appendix C).

5.4 Dyadic Level Analysis

To better understand changes in communication and collaboration directly with the controlling entity, we construct a dyadic level dataset of R&D subsidiary-control entity-year observations. The sample had 6,854 R&D subsidiary-control entity-year observations on 1,440 subsidiary-control entity relationships. The dependent variables are dyadic outcomes of the number of subsidiary patents co-invented with the control entity in the focal year, the quality and total market value of those co-invented patents, and knowledge flows from the control entity to the R&D subsidiary. Following prior research, we constructed dyadic control variables based on the average of the R&D subsidiary and control entity's value for each control variable (Forman and van Zeebroeck, 2019). Standard errors were clustered at the dyadic level.

6. Results

We start with a subsidiary-level analysis of the full sample because a controlling entity can influence subsidiary-level outcomes such as total innovation or collaboration across MNE entities. Given the potential for systematic differences between headquarters- and subsidiary-controlled R&D subsidiaries, we then focus on the matched sample results. Next, we study the dyadic relationships for innovation outcomes of collaboration and knowledge flows specifically with the controlling entity. Finally, we perform subsample dyadic analyses on R&D subsidiaries that have both headquarters and subsidiaries controlling their R&D to study within-subsidiary differences in headquarters versus subsidiary control in response to broadband.

6.1 The First-Order Impact of Broadband on Innovation

Table 2 columns 1, 7, and 13 show the results based on the difference-in-differences specification detailed in equation (1) for the overall effects of broadband technology on R&D subsidiary innovation. In column 1, the dependent variable is *Innovation Quantity*. The coefficient for post-broadband introduction is positive and statistically significant at the $p < 0.001$ confidence level, indicating that after the introduction of broadband, the non-logged number of patents generated by R&D subsidiaries increases, on average, 9.1 percent. Broadband is also associated with more impactful innovations. Column 7 shows a point estimate of 0.176 ($p < .001$) for *Innovation Quality* indicating that, on average, an R&D subsidiary has a 19.2 percent increase in the non-logged number of forward citations on its invented patents relative to those that did not

have broadband technology introduced. The coefficient in Column 13 indicates that post-broadband, R&D subsidiaries, on average, increased their non-logged market value of innovations by 21.8 percent. Altogether, the results underscore the economic significance of broadband for firm innovation.

-----Insert Table 2 here-----

6.2 Innovation by Controlling Entity Across Broadband Levels

Figure 1 shows innovation quantity for R&D subsidiaries controlled by headquarters versus subsidiaries across levels of broadband technology penetration. The vertical axis displays innovation quantity, and the horizontal axis displays the broadband penetration rate. The red line and triangles represent R&D subsidiaries controlled by headquarters, and the blue line and squares represent R&D subsidiaries controlled by subsidiaries. On the left, the graph contains the full sample of raw data. Figure 1 shows that as broadband penetration rate increases, subsidiary-controlled R&D subsidiaries have an increasing number of patents produced. In contrast, headquarters-controlled R&D output stays relatively stable. The graph on the right isolates the effects for R&D subsidiaries controlled by only headquarters versus only subsidiaries. As the broadband penetration rate increases, headquarters-controlled R&D subsidiaries produce less innovation.

-----Insert Figure 1 Here -----

6.3 Results for Headquarters- vs Subsidiary-Controlled R&D

The remainder of our empirical analyses focus on comparing the effect of broadband on headquarters- versus subsidiary-controlled R&D subsidiaries. We estimate the triple difference specification detailed in equation (2). Table 2 contains the baseline results. The dependent variable is *Innovation Quantity* in columns 2-6. In column 2, we estimate the model without any time-varying controls and in Column 3 we incorporate country-, MNE-, and subsidiary-level time-varying controls for the full sample. We then estimate the effects on the matched sample for the model without any time-varying controls (column 4), before adding country- and MNE-level time varying controls (column 5), followed by including subsidiary time-varying controls (column 6). Columns 8-12 and 14-18 reflect the same pattern with *Innovation Quality* and *Innovation Market Value* as the dependent variables, respectively.

The results in Table 2 are consistent with the patterns in Figure 1. After the introduction of broadband technology, there is a positive and significant mean shift in innovation quantity, quality, and market value for subsidiary-controlled R&D subsidiaries. The point-estimate for the *Post-broadband* coefficient in Column 5 is 0.136, which equates to an average increase of 14.6 percent in the non-logged number of patents generated by subsidiary-controlled R&D subsidiaries in countries where broadband was introduced relative to those in countries where broadband had not yet been introduced at that time. In contrast, the change in innovation for headquarters-controlled R&D subsidiaries post-broadband relative to headquarters-controlled R&D subsidiaries without broadband at the time is 14.5 percentage points smaller than subsidiary-controlled ones.

Columns 8-12 report the results for *Innovation Quality*. A similar pattern emerges. The estimated coefficient in Column 11 for headquarters-controlled post-broadband indicates a smaller change of 44.6 percent in the non-logged number of forward citations received by headquarters- compared to subsidiary-controlled R&D subsidiaries, using the change in the differential performance of headquarters- relative to subsidiary-controlled R&D subsidiaries in unaffected regions as a baseline.

The results for *Innovation Market Value* in Columns 14-18 indicate that headquarters-controlled R&D subsidiaries also had a significantly smaller change in the market value of innovations after broadband introduction. The results in Column 17 indicate that R&D subsidiaries controlled by other subsidiaries had a 31.9 percent increase in the non-logged market value of their innovations produced, relative to R&D subsidiaries controlled by other subsidiaries that did not have broadband technology introduced at that time. In contrast, headquarters-controlled R&D subsidiaries experienced a 31.5 percent smaller change in the non-logged innovation market value post-broadband than subsidiary-controlled.

Overall, the results indicate that headquarters-controlled R&D subsidiaries do not experience the same level of positive innovation outcomes after communication technology is introduced. After broadband introduction, headquarters-controlled R&D subsidiaries have a significantly smaller change in innovation quantity, quality, and market value than subsidiary-controlled ones.

6.4 Empirical Assessments

We discuss several potential methodological concerns to using broadband introduction as an exogenous shock and present assessments of pre-treatment trends, different treatment thresholds, and placebo tests.

The main methodological concern with Table 2 is that broadband introduction might anticipate (or lead) changes in innovation opportunities for subsidiaries. Figure 2 plots the average for headquarters- relative to subsidiary-controlled R&D subsidiaries with broadband introduction event time dummies for each four-year period relative to the time of broadband introduction. The solid (dotted) line plots the estimated coefficients (95th confidence interval) of the broadband introduction event time dummies. Figure 2 shows no significant trend before broadband introduction as the coefficients are statistically indistinguishable from zero. After broadband introduction, however, the trend changes, with the coefficient beginning to decrease after broadband introduction and remaining negative over time.

----Insert Figure 2 here----

In sensitivity analyses, we apply different thresholds of broadband penetration by creating separate binary indicators for a broadband penetration rate of 3, 7, and 10 percent and find generally consistent results. Table C.3 in Appendix C indicates that as the broadband penetration rate increases, the difference between headquarters- versus subsidiary-controlled R&D subsidiaries remains economically significant.

We conducted placebo tests by creating one, two, and three-year leads on the post broadband variable and interaction term with headquarters-controlled. The coefficients for the one, two, and three-year leading post-broadband main and interaction terms were non-significant (see Table C.4 in Appendix C).

7 Evaluating Underlying Factors Explaining the Effects

7.1 Centralization of R&D

One potential explanation for the results is that if the MNE has delegated control over most of the R&D activities, headquarters might not have the insight to coordinate collaboration and knowledge sharing across the subsidiary group. If this were the case, then we would expect to find that when headquarters holds control over more R&D subsidiaries the difference between subsidiary- versus headquarters-

controlled R&D subsidiaries will be smaller. Splitting the sample based on the median number of headquarters-controlled R&D subsidiaries, we do not find evidence of this explanation. The coefficient for headquarters-controlled post-broadband is negative and significant for both centralized (high) and decentralized (low) control of R&D in the full sample. For the matched sample, they are non-significant (see Table C.5 in Appendix C).

7.2 Changes in R&D Funding

If there are greater information asymmetries for subsidiary- than headquarters-controlled R&D subsidiaries, then a change in communication can alleviate those information asymmetries and lead to more funding of subsidiary-controlled R&D. To test this alternative explanation, we apply the natural log of R&D expenditures as an alternative dependent variable. As shown in Table C.6 in Appendix C, the change in R&D expenditures for headquarters-controlled versus subsidiary-controlled R&D subsidiaries is statistically indistinguishable from zero. Thus, we do not find evidence that the larger increase in innovation outcomes for subsidiary-controlled R&D is the result of a reallocation of financial resources.

7.3 Approaches to Innovation

While changes in innovation quality and quantity demonstrate changes in innovative productivity after the introduction of broadband, they tell us little about how broadband altered the approach to innovation, such as whether the R&D subsidiary became more collaborative or pursued more novel, exploratory projects (Balsmeier et al., 2017). We examine an additional set of patent-based measures to understand better the mechanisms driving the larger increase in innovation for subsidiary-controlled R&D subsidiaries.

7.3.1 Changes in co-invention

Communication technologies can facilitate collaboration (Agrawal and Goldfarb, 2008; Ding et al., 2010; Forman and van Zeebroeck, 2019; Forman and Van Zeebroeck, 2012), and collaboration across subsidiaries within an MNE yields superior innovation outcomes in terms of innovation quantity and quality (Singh, 2008). Thus, the increase in innovation may be driven by collaborative behaviors. If headquarters has additional attention demands, it might not sufficiently invest attention in brokering collaboration.

Table 3, columns 1–2, contain the results for estimations using co-invented patents as the dependent variable. The 0.119 ($p=0.01$) coefficient estimate in column 2 for subsidiary-controlled indicates that these subsidiaries see an average increase of 12.6 percent in the non-logged quantity of co-invented patents after broadband relative to subsidiary-controlled R&D without broadband at that time. Column 2 indicates that the effect of broadband on changes in co-inventions for headquarters-controlled R&D subsidiaries is 14.0 percentage points smaller ($p=0.05$) than for subsidiary-controlled R&D.

Columns 3-4 contain the results for patents invented solely by the R&D subsidiary. The results do not provide evidence of significant changes in sole-invented patents, regardless of whether an R&D subsidiary is subsidiary- or headquarters-controlled. This suggests that the increase in innovation is from increases in collaboration and that R&D subsidiaries are not substituting sole with collaborative innovations.

----Insert Table 3 here----

The results imply that headquarters was less effective than subsidiaries in coordinating collaboration in the R&D subsidiaries they controlled post-broadband introduction. This finding counters the prevalent idea that the headquarters is the principal “orchestrator” of knowledge for subsidiaries.

7.3.2 Changes in innovation scope

Increases in innovation scope reflect a shift towards more exploratory search processes in R&D as firms integrate new knowledge, which is riskier and increases the probability of generating especially valuable patents (Fleming, 2001; Katila and Ahuja, 2002). We analyze the effects of broadband introduction on innovation scope. The results in Table 3 column 6 indicate that innovation scope increases for subsidiary-controlled R&D subsidiaries by an average of 12.0 percent post-broadband introduction relative to those in untreated areas. In contrast, headquarters-controlled R&D subsidiaries have a 12.4 percentage point smaller change in innovation scope post-broadband than subsidiary-controlled ones.

The main implication of the results is that increases in collaborative and exploratory innovation outcomes are more prevalent in subsidiary- than headquarters-controlled R&D subsidiaries after broadband

introduction. The results are consistent with the headquarters devoting less time and effort in using communication technologies to facilitate collaboration and foster innovation with high-quality monitoring.

7.4 Heterogeneity in Demands for Attention

We perform split sample analyses and explore several conditions under which limited attention as a channel would be more salient. Arguably, the larger the firm, the greater the information-processing demands on headquarters and the lower the attention headquarters can pay to each unit (Dessein, 2002; Garicano, 2000). Similarly, diversified firms require significant attention towards diverse market factors that drive performance in their various industries. All else equal, headquarters of highly diversified firms face greater complexities to manage the diverse portfolio. Managers can become spread too thinly, limiting the amount of attention they can pay to specific industries or regions. Additionally, communication complexities such as when the R&D subsidiary is culturally distant or speaks a different language requires the controlling entity to invest more effort to broker collaboration and perform higher-quality monitoring. We expect that the effects of limited attention will be more salient when there are such complexities.

----Insert Table 4 here----

In Table 4, we split the sample based on the median value of MNE size, MNE diversification, and cultural distance between headquarters and the R&D subsidiary. Consistent with expectations, columns 1-2 and 3-4 in Table 4 show that the significantly smaller change in innovation is strongest for headquarters-controlled R&D subsidiaries of large and highly diversified MNEs, respectively. Moreover, columns 5 through 8 in Table 4 indicate that headquarters controlled R&D have significantly smaller changes in innovation post-broadband compared to subsidiary-controlled when across-company exchanges are fraught with communication complexities. Specifically, the difference is greater for culturally and linguistically distant locations from the headquarters.

7.5 Dyadic Analyses

This section further investigates the channels of collaboration and knowledge flows between the controlling entity and the R&D subsidiary with a dyadic-level analysis.

7.5.1 Changes in collaboration with headquarters versus subsidiary-controlled entities

The co-invented patents in Table 3 represent all patents co-invented by the R&D subsidiary with any entity from the MNE group. Controlling entities may broker collaboration between subsidiaries within the firm or collaborate directly with the R&D subsidiary. This analysis examines direct collaboration between the control entity and the R&D subsidiary. Table 5 column 2 indicates that R&D subsidiaries controlled by subsidiaries had a significant increase of 5.5 percentage points ($p > .001$) in innovations co-invented with their controlling subsidiary. In contrast, R&D subsidiaries controlled by headquarters had a 7.7 percentage point ($p < .01$) smaller change in innovations co-invented with headquarters. In column 4, we examine the change for R&D subsidiaries controlled by both types of MNE entities. The analysis indicates that subsidiaries under the control of both headquarters and subsidiaries had an 8.1 percentage point ($p < .01$) increase in collaborative innovations with their controlling subsidiary and a 11.3 percentage point smaller change in collaborative innovations with headquarters ($p < .01$).

To understand the extent to which these collaborations are economically important, we calculated the total innovation quality and market value of the co-invented patents with the control entity. Columns 5-12 provide consistent evidence of a larger increase in the quality and market value of innovations co-invented under the control of subsidiaries than headquarters. In the full sample, headquarters-controlled R&D had 15.3 and 18.5 percentage point smaller changes in the quality and market value of their collaborative innovations, respectively, compared to subsidiary-controlled R&D. The difference is starker for the subsample of subsidiaries that perform R&D projects for headquarters and subsidiaries. These subsidiaries had 21.2 and 29.9 percentage point smaller changes in the quality and market values of innovations co-invented with a controlling headquarters compared to those co-invented with a controlling subsidiary.

----Insert Table 5 here---

7.5.2 Changes in knowledge flows

An increase in prior art citations (backward citations) from an R&D subsidiary to prior art from a controlling entity reflects an improvement in communication between the controlling entity and the R&D

subsidiary (Sorenson et al., 2006). If headquarters and subsidiaries are using broadband to communicate, we should see an increase in these knowledge flows between the controlling entities and the R&D subsidiaries that they control. Table 5, columns 13-16, contain the results to analyses where the dependent variable is knowledge flows with the controlling entity. The R&D subsidiaries exhibit a 13.5 percentage point larger increase ($p < .05$) in backward citations to their controlling subsidiary post-broadband than headquarters. The results provide evidence that post-broadband introduction, subsidiaries with control rights more effectively increase knowledge transfer to R&D subsidiaries than headquarters.

7.5.3 Attention and technological expertise

When attention is limited, managers often “manage by style” – that is, they focus their attention on managing areas close to their expertise above those more distant (Lo et al., 2021). We examine this as a potential mechanism. We employ a dyadic measure of the Euclidean distance between patent portfolios of the subsidiary and its controlling entity (headquarters or subsidiary) as a measure of differences in technological expertise (see, e.g., Ahuja, 2000). Splitting the sample based on the median technological distance between controlling entity and R&D subsidiary in Table 6, we do not find evidence of controlling subsidiaries having limited attention and “managing by style.” Technologically distant R&D subsidiaries significantly increase their collaborative innovations with the controlling subsidiary despite technological distance. In contrast, columns 1-4 indicate that R&D subsidiaries have a significantly smaller change in collaboration when headquarters is technologically distant. This suggests that, unlike subsidiaries, headquarters is managing by style in that it is devoting less attention to areas distant from its expertise.

----Insert Table 6 here----

7.6 Robustness Checks

We perform a variety of robustness tests. We examine the sensitivity of the analyses to using the non-logged total patent counts as dependent variables with negative binomial estimation. The analyses indicated that the findings are not driven by functional form. We also estimated the analyses on 1) the initial sample of all R&D subsidiaries, and 2) estimated difference-and-differences analyses separately for the samples of

a) headquarters-controlled R&D subsidiaries and the sample of b) subsidiary-controlled R&D subsidiaries. The results were qualitatively similar using these alternative samples. Finally, because there might be systematic differences in MNEs (including MNE tendency to adopt broadband once introduced in a region), we incorporated MNE-year fixed effects and found consistent results.

8 Conclusion

One of the most critical productivity puzzles of the last half-century is why the returns to information and communication technologies are so large and heterogeneous between firms (Aghion et al., 2014; Brynjolfsson and Hitt, 2003; Stiroh, 2002). Communication technologies have radically changed our world and how individuals and businesses interact. A revolutionary technology for firms was broadband, which enabled the richness of interactions with two-way data transfers, video, and large data transmissions at fast speeds across large distances. Difficulty in transferring knowledge and information across organizational units creates well-documented challenges for innovation management (Balsmeier et al., 2017; He and Tian, 2018; Manso, 2011; Seru, 2014; Teece, 2010, 1977). Our study provides novel insight into whether and when firms exploit the potential benefits of communication technologies to improve innovation outcomes.

This paper contributes to the literature examining how communication technologies affect innovation by providing evidence that it is a function of the delegation of control. After broadband introduction, headquarters-controlled R&D subsidiaries have a significantly smaller change in innovation outcomes. Moreover, control rights affect not merely the productivity of patenting but also the innovation process itself: subsidiary-controlled R&D subsidiaries shift to more collaborative and exploratory approaches. The results indicate that headquarters fail to leverage the benefits of communication technologies fully. A key implication is that intra-firm control rights can influence the overall returns to communication technology.

The introduction of broadband creates a shock to the information available, which can be more salient for headquarters than subsidiaries because it has group-wide responsibility for the MNE. We find a pattern of results consistent with the attention demands on headquarters constraining its effectiveness in leveraging communication technologies to foster innovation. Headquarters of large, diverse MNEs that control

culturally and linguistically different subsidiaries are less effective than subsidiaries in exploiting access to technology to foster innovation outcomes. Our findings that the effects are stronger when the R&D subsidiary is technologically distant from headquarters is aligned with work that has shown that top management has limited attention and tend to “manage by style” when information processing demands are high by focusing on operations closest to its expertise (Lo et al., 2021).

We contribute to the literature on the management of innovation (Aghion and Tirole, 1994; Arora et al., 2014; Seru, 2014) by studying the effects of subsidiaries controlling other subsidiaries’ R&D activities. Although innovation is considered a key driver of MNE financial performance (Teece, 2010, 1977), we still know relatively little about how the interim level of control based on subsidiaries managing other subsidiaries affects innovation. The stark difference that we identify between headquarters- and subsidiary-controlled innovation highlights the importance of distinguishing subsidiary-subsidiary authority relationships and studying their implications for strategic outcomes. Despite the emphasis in the existing literature on headquarters role in managing R&D activities, we find that subsidiaries play an increasingly important role. The positive effect of broadband on innovation emerged almost entirely through subsidiary-controlled R&D. Given the ability to communicate, subsidiaries effectively can facilitate knowledge flows, collaboration, and foster motivation to integrate new knowledge. Consequently, subsidiary-controlled R&D subsidiaries produced more innovations and more impactful innovations with greater market value.

Finally, our results provide further evidence for the importance of accounting for control rights in studying innovation and market performance (Elfenbein and Lerner, 2003; Leiponen, 2008; Lerner et al., 2003; Lerner and Merges, 1998). Our study suggests that the emergence of new technologies can alter the kind of controlling entity that can maximize value creation. Pre-broadband, headquarters appeared at least as equipped as subsidiaries to manage R&D subsidiaries. Post-broadband, headquarters is relatively less effective than subsidiaries at fostering innovation in the R&D subsidiaries it controls. Subsidiary-controlled R&D subsidiaries, while once less innovative, were able to overtake headquarters-controlled ones in terms of productivity, innovativeness, market value, and collaboration.

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Tables and Figures

Table 1 Descriptive Statistics of R&D Subsidiaries by Controlling Entity

Variable	Number of Observations	All	Headquarters- Controlled	Subsidiary- Controlled	Headquarters- Controlled Only	Headquarters and Subsidiary- Controlled	Subsidiary- Controlled Only
Panel A: Pre-Broadband							
Innovation Quantity	1,570	0.282	0.233	0.270	0.336	0.168	0.340
Innovation Quality	1,311	0.321	0.327	0.270	0.531	0.213	0.306
Innovation Market Value	1,481	0.514	0.381	0.519	0.516	0.299	0.672
Panel B: Post-Broadband							
Innovation Quantity	2,439	0.483	0.303	0.568	0.298	0.335	0.716
Innovation Quality	1,726	0.565	0.407	0.625	0.465	0.385	0.805
Innovation Market Value	2,112	0.760	0.416	0.937	0.388	0.477	1.266
Panel C: Full Sample							
Innovation Quantity	4,009	0.404	0.276	0.446	0.312	0.262	0.567
Innovation Quality	3,037	0.460	0.373	0.462	0.489	0.302	0.579
Innovation Market Value	3,593	0.659	0.402	0.755	0.434	0.396	1.011

Notes. This table contains the respective sample mean values of Innovation Quantity, Quality, and Market Value. The full sample is composed of subsidiaries performing R&D activities that are managed by headquarters or another subsidiary. Pre-broadband represents the sample of R&D subsidiaries before broadband technology is introduced in both the R&D subsidiary and its controlling entity country locations. Post-broadband represents the sample of R&D subsidiaries after broadband technology is introduced in both the R&D subsidiary and controlling entity country locations. Innovation Quantity is the total number of patents produced by a subsidiary in a given year. Innovation Quality is the number of forward citations received over the five-year period after patent grant date. Innovation Market Value is the total market-adjusted MNE returns (millions of dollars) on the three-day window following the patent issue date for the patents invented by the focal R&D subsidiary in that year, deflated to 1982 using the CPI. Innovation Quantity, Quality, and Market Value reflect the natural logarithm values of innovation outcomes plus one. The full sample is used for Innovation Quantity. The sample years are restricted to 1997-2009 for Innovation Quality in order to reduce problems with right censoring of forward citations. Innovation Market Value has a smaller number of observations due to missing patent market values in the database (see Kogan et. al (2017) for missing data circumstances).

Table 2 The Effect of Broadband on Innovation by Type of Entity Controlling R&D

	Innovation Quantity						Innovation Quality						Innovation Value					
	Full Sample			Matched Sample			Full Sample			Matched Sample			Full Sample			Matched Sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Post-Broadband Introduction	0.087 (0.027) [0.001]	0.162 (0.038) [0.000]	0.184 (0.039) [0.000]	0.132 (0.053) [0.013]	0.136 (0.053) [0.010]	0.209 (0.049) [0.000]	0.176 (0.052) [0.001]	0.334 (0.086) [0.000]	0.387 (0.091) [0.000]	0.401 (0.123) [0.001]	0.429 (0.118) [0.000]	0.427 (0.118) [0.000]	0.197 -0.063 [0.002]	0.329 -0.091 [0.000]	0.350 -0.114 [0.002]	0.263 (0.102) [0.011]	0.277 (0.102) [0.007]	0.454 (0.143) [0.002]
Headquarters-Controlled* Post-Broadband Introduction		-0.164 (0.050) [0.001]	-0.184 (0.059) [0.002]	-0.166 (0.067) [0.014]	-0.145 (0.066) [0.029]	-0.206 (0.062) [0.001]		-0.275 (0.106) [0.010]	-0.359 (0.119) [0.003]	-0.335 (0.140) [0.017]	-0.369 (0.139) [0.008]	-0.364 (0.138) [0.009]		-0.300 -0.116 [0.010]	-0.315 -0.144 [0.029]	-0.314 (0.135) [0.020]	-0.274 (0.137) [0.046]	-0.451 (0.170) [0.008]
Subsidiary Controls	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Country and MNE Controls	No	No	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Headquarter-Controlled-Year Fixed Effects	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Number of Observations	4009	3961	2596	1361	1311	1154	3037	3037	2340	1125	1085	1056	3593	3554	2406	1207	1162	1043
Number of Clusters	946	941	721	282	282	282	857	857	693	276	276	275	911	906	694	266	266	263
R-squared	0.052	0.060	0.047	0.085	0.093	0.114	0.024	0.033	0.036	0.081	0.093	0.097	0.032	0.039	0.040	0.050	0.062	0.084

Notes. This table presents the difference-in-difference estimates of the introduction of broadband technology and innovation outcomes in columns 1, 7, and 13. The remaining columns contain the triple difference estimates of the effect of broadband introduction on the innovation of R&D subsidiaries controlled by headquarters vis-à-vis those controlled by other subsidiaries. The matched sample uses a vector of mean pre-treatment variables that can affect innovation outcomes. Post-broadband introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for both the R&D subsidiary-country and the controlling-entity country. Headquarters-controlled*Post-broadband introduction reflects the interaction term of the binary indicator for headquarters-controlled R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-controlled R&D subsidiary is absorbed by subsidiary fixed effects. Innovation Quantity represents the natural log plus one of the patents invented by the R&D subsidiary in the given year. Innovation Quality is the natural log plus one of the total number of forward citations received by the R&D subsidiary in five years for the patents invented in the current year. Innovation Market Value is the natural log of total market-adjusted MNE returns (millions of dollars) on the three-day window following the patent issue date for the patents invented by the focal R&D subsidiary in that year, deflated to 1982 using the CPI. 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 3 The Effect of Broadband on Collaborative Innovation and Innovation Scope

	Co-Invented Innovation		Sole-Invented Innovation		Innovation Scope	
	(1)	(2)	(3)	(4)	(5)	(6)
Post-Broadband Introduction	0.120 (0.046) [0.009]	0.119 (0.046) [0.009]	0.030 -0.037 [0.430]	0.035 -0.037 [0.340]	0.112 (0.048) [0.020]	0.120 (0.048) [0.013]
Headquarters-Controlled* Post-Broadband Introduction	-0.169 (0.058) [0.004]	-0.140 (0.058) [0.017]	-0.044 -0.050 [0.370]	-0.043 -0.047 [0.365]	-0.110 (0.059) [0.062]	-0.124 (0.058) [0.033]
Country and MNE Controls	No	Yes	No	Yes	No	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Headquarter-Controlled-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	1361	1311	1361	1311	1218	1178
Number of Clusters	282	282	282	282	282	282
R-squared	0.090	0.100	0.060	0.070	0.057	0.065

Notes. Estimated on the matched sample of headquarters-controlled to subsidiary-controlled R&D subsidiaries. The dependent variable for columns 1 and 2 is the natural log of one plus the total number of patents co-invented by the focal R&D subsidiary and another MNE entity. The dependent variable for columns 3 and 4 is the natural log of one plus the total number of patents invented only by the focal subsidiary. The dependent variable for columns 5 and 6 is innovation scope, measured as the proportion of new-to-the-subsidary citations to prior art that the subsidiary had not previously cited in the last five years to total citations to prior art in the given year. Post-broadband introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for both the R&D subsidiary-country and the controlling entity country. Headquarters-controlled*Post-broadband introduction reflects the interaction term of the binary indicator for headquarters-controlled R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-controlled R&D subsidiary is 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. All tests are two-tailed.

Table 4 Exploring Heterogeneity in the Effect of Broadband on Innovation

	Firm Size		Firm Diversification		Cultural Distance		Same	Different
	High	Low	High	Low	High	Low	Language	Language
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post-Broadband Introduction	0.163 (0.062) [0.010]	0.041 (0.038) [0.287]	0.154 (0.062) [0.013]	0.096 (0.103) [0.353]	0.139 (0.049) [0.005]	0.178 (0.129) [0.169]	0.238 (0.153) [0.123]	0.162 (0.051) [0.002]
Headquarters-Controlled* Post-Broadband Introduction	-0.305 (0.113) [0.008]	0.015 (0.056) [0.783]	-0.157 (0.070) [0.027]	-0.079 (0.117) [0.498]	-0.195 (0.063) [0.003]	-0.065 (0.151) [0.666]	-0.189 (0.159) [0.239]	-0.159 (0.065) [0.016]
Country and MNE Controls	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
Headquarter-Controlled-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	658	653	648	663	680	620	439	794
Number of Clusters	156	146	137	181	142	137	98	184
R-squared	0.150	0.093	0.173	0.105	0.103	0.146	0.199	0.102

Notes. Estimated on the matched sample of headquarters-controlled to subsidiary-controlled R&D subsidiaries. Columns 1 and 2 represent split sample analyses where the matched sample is split based on the median of MNE size. Columns 3 and 4 contain results for the sample split based on the median of MNE Diversification. For Columns 5 and 6 the sample is split based on the median cultural distance and for columns 7 and 8 the sample is based on whether the R&D subsidiary country has the same versus a different official language as the headquarters country. The dependent variable is innovation quantity calculated as the natural log of one plus the total number of patents invented by R&D subsidiary in the given year. Post-broadband introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for both the R&D subsidiary-country and the controlling entity country. Headquarters-controlled*Post-broadband introduction reflects the interaction term of the binary indicator for headquarters-controlled R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-controlled R&D subsidiary is 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. All tests are two-tailed.

Table 5 Dyadic Analysis of the Effects of Broadband on R&D Subsidiary Collaboration and Knowledge Flows with Controlling Entity

	Co-Inventions with Control Entity				Co-Invention Innovation Quality				Co-Invention Market Value				Knowledge Flows			
	All Dyadic Control Relationships		Both Headquarters and Subsidiary Controlled		All Dyadic Control Relationships		Both Headquarters and Subsidiary Controlled		All Dyadic Control Relationships		Both Headquarters and Subsidiary Controlled		All Dyadic Control Relationships		Both Headquarters and Subsidiary Controlled	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Post-Broadband Introduction	0.058 (0.014) [0.000]	0.055 (0.015) [0.000]	0.080 -0.029 [0.005]	0.081 -0.031 [0.010]	0.101 (0.036) [0.006]	0.098 (0.039) [0.012]	0.115 (0.065) [0.079]	0.107 (0.070) [0.126]	0.138 (0.046) [0.003]	0.135 (0.049) [0.006]	0.233 (0.092) [0.012]	0.248 (0.102) [0.016]	0.094 (0.026) [0.000]	0.098 (0.029) [0.001]	0.088 (0.045) [0.052]	0.103 (0.051) [0.042]
Headquarters-Controlled* Post-Broadband Introduction	-0.077 (0.028) [0.006]	-0.077 (0.029) [0.008]	-0.124 -0.042 [0.004]	-0.113 -0.043 [0.008]	-0.139 (0.068) [0.040]	-0.153 (0.072) [0.034]	-0.219 (0.097) [0.024]	-0.212 (0.099) [0.033]	-0.187 (0.069) [0.007]	-0.185 (0.074) [0.013]	-0.303 (0.107) [0.005]	-0.299 (0.115) [0.010]	-0.123 (0.047) [0.010]	-0.136 (0.053) [0.010]	-0.126 (0.061) [0.041]	-0.135 (0.065) [0.040]
Country and MNE Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Dyad Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Headquarter-Controlled-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	6854	6299	2319	2162	6427	5903	2196	2056	6503	5975	2231	2089	6854	6299	2319	2162
Number of Clusters	1440	1310	470	433	1417	1290	459	425	1418	1291	459	425	1440	1310	470	433
R-squared	0.024	0.024	0.044	0.045	0.024	0.025	0.054	0.052	0.02	0.021	0.045	0.046	0.015	0.016	0.016	0.02

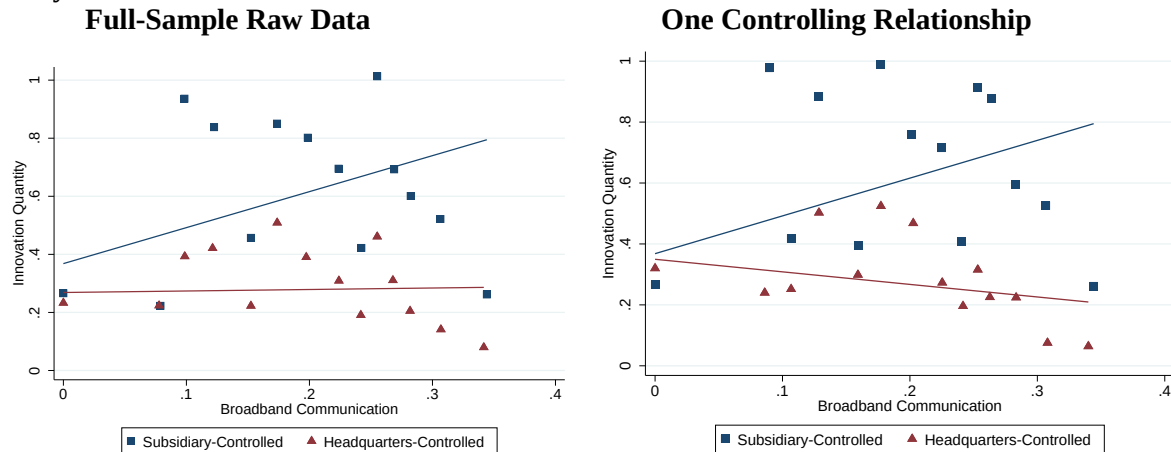
Notes. This table contains the dyadic level triple difference estimates of the effect of broadband introduction on the co-inventions and knowledge flows of R&D subsidiaries controlled by headquarters vis-à-vis those controlled by other subsidiaries. All Dyadic Control Relationships contains all R&D-subsidiary-control entity-year observations. The Both Headquarters and Subsidiary Controlled sample contains the R&D-subsidiary-control entity-year observations for R&D subsidiaries that performed R&D projects for both headquarters and subsidiaries. The dependent variable in columns 1-4 is Co-inventions with Control Entity, measured as the natural log plus one of the total number of innovations that the R&D subsidiary co-invented with the focal control entity. The dependent variable Co-invented Innovation Quality in columns 5-8 is the natural log plus one of the total number of forward citations received by the R&D subsidiary in five years for the patents co-invented with the focal control entity in the current year. In columns 9-12, Innovation Market Value is the dependent variable and is measured as the natural log of the total market-adjusted MNE returns (millions of dollars) on the three-day window following the patent issue date for the patents co-invented by the R&D subsidiary and the focal control entity in that year, deflated to 1982 using the CPI. The dependent variable Knowledge Flows in Columns 13-16 is the proportion of R&D subsidiary citations in a given year to prior art invented by the control entity that the R&D subsidiary had not previously cited in the past five years. Post-broadband introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for both the R&D subsidiary-country and the controlling entity country. Headquarters-controlled*Post-broadband introduction reflects the interaction term of the binary indicator for headquarters-controlled R&D subsidiary dyadic tie with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-controlled R&D is absorbed by dyadic fixed effects. All models are estimated using fixed effects OLS with robust standard errors clustered at the dyadic level. Standard errors are in parentheses and p-values are in brackets.

Table 6 The Effect of Broadband on Co-Invention with Controlling Entity by High vs Low Technological Distance

	Technical Distance High				Technical Distance Low			
	Dyadic Control Relationships		Both Headquarters and Subsidiary Controlled		Dyadic Control Relationships		Both Headquarters and Subsidiary Controlled	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post-Broadband Introduction	0.053 (0.016) [0.001]	0.056 (0.019) [0.004]	0.073 (0.026) [0.005]	0.055 (0.030) [0.064]	0.067 (0.033) [0.042]	0.067 (0.031) [0.029]	0.054 (0.048) [0.264]	0.106 (0.062) [0.089]
Headquarters-Controlled* Post-Broadband Introduction	-0.112 (0.046) [0.016]	-0.101 (0.049) [0.039]	-0.173 (0.062) [0.006]	-0.132 (0.064) [0.038]	-0.054 (0.037) [0.149]	-0.047 (0.037) [0.201]	-0.048 (0.055) [0.378]	-0.067 (0.070) [0.335]
Country and MNE Controls	No	Yes	No	Yes	No	Yes	No	Yes
Dyad Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Headquarter-Controlled-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	3210	2887	1168	1032	3192	2877	1149	1012
Number of Clusters	624	577	226	216	667	597	248	221
R-squared	0.028	0.028	0.055	0.063	0.042	0.047	0.086	0.113

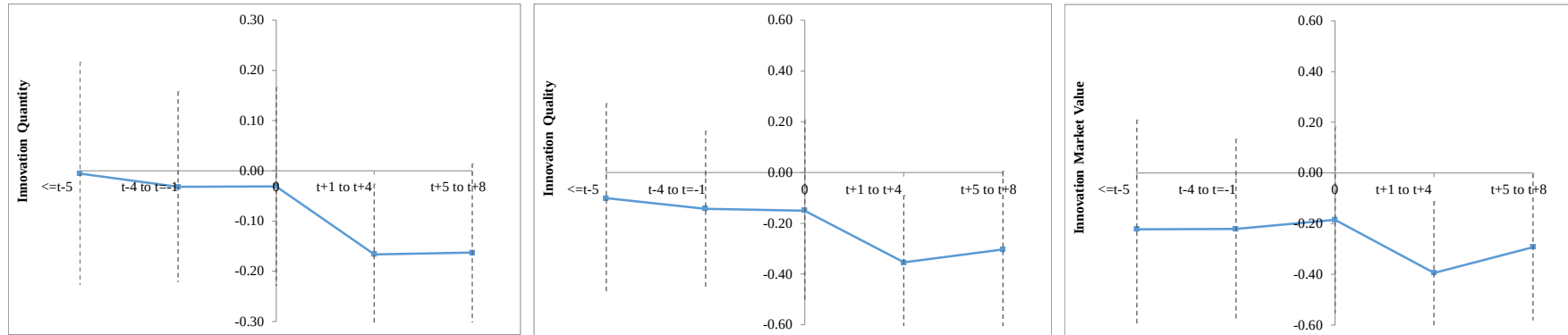
Notes. Estimations for columns 1-2 and 3-4 in Table 5 split based on the sample median technological distance between R&D subsidiary and the focal control entity. The dependent variable is Co-inventions with Control Entity, measured as the natural log plus one of the total number of innovations that the R&D subsidiary co-invented with the focal control entity. Post-broadband introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for both the R&D subsidiary-country and the controlling entity country. Headquarters-Controlled*Post-Broadband Introduction reflects the interaction term of the binary indicator for headquarters-controlled R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-controlled R&D subsidiary is absorbed by subsidiary fixed effects. All models are estimated using fixed effects OLS with robust standard errors clustered at the dyad level. Standard errors are in parentheses and p-values are in brackets. All tests are two-tailed.

Figure 1 Binscatter Plots for Innovation Quantity and Broadband Penetration by Controlling Entity



Notes. These figures plot innovation quantity across the broadband penetration rate in the R&D subsidiary's location by R&D subsidiary control relationship (subsidiary versus headquarters controlled) for 1997-2011 for the full sample (graph on left) and the sample of R&D subsidiaries that are controlled by only one MNE entity (graph on right). Innovation quantity is the natural log of one plus the number of successful patents filed in a given year by the focal R&D subsidiary. To account for both the R&D subsidiary and the controlling entity needing broadband access to effectively utilize it, each R&D subsidiary's country broadband communication value equals to zero until the first year that its control entity has at least five percent broadband penetration rate, at which point broadband communication in the graphs equal the R&D subsidiary's host-country broadband penetration rate.

Figure 2 Triple Differences Pre-Treatment Trends for Innovation Output



Notes. The graphs above are based on the specifications of Models 6, 12, and 18 in Table 2, with the Headquarters-Controlled*Post-Broadband Introduction split into multiple periods as indicated. Each point on the graphs represent the coefficient value of the Headquarters-Controlled*Post-Broadband Introduction binary indicators. The dashed lines represent the 95 percent confidence interval. The confidence intervals are larger in the figures than in the estimates in Table 2 due to the reduced degrees of freedom since the Headquarters-Controlled*Post-Broadband Introduction variable is split into separate binary indicators for each period.

Appendix A

Example from Contract R&D Agreement

Below are redacted clauses from a randomly selected R&D contract between two subsidiaries.

[Subsidiary B] shall promptly undertake each Project ... and shall use its best efforts to complete the Project in accordance with the specifications and directions of [Subsidiary A].

[Subsidiary B] shall provide monthly reports to [Subsidiary A] on the progress that has been made with respect to the Projects. Each Report shall contain.....

[Subsidiary B] acknowledges [Subsidiary A] 's exclusive right, title, and interest in and to the Intangible Property....Every use of any Intangible Property by [Subsidiary B] shall inure to the benefit of [Subsidiary A].

[Subsidiary A] shall at all times, during or after the term of this Agreement, be the sole owner of all rights relating to or emanating from Intangible Property, Know-How, Improvements, or other matters developed in, or related to, a Project.

Appendix B

Redacted Description from Transfer Pricing Report

Note: All redactions are in brackets. Subsidiary and MNE names, country locations, and product, technology, and industry descriptions are redacted to maintain confidentiality. To keep example succinct, we include the description of only one subsidiary's (Subsidiary B) controlled R&D activities and not all three R&D subsidiaries.

[Subsidiary A] designs and manufactures [MNE]'s [Products], with the exception of certain products designed and manufactured in [Country]. Design activities include "blue sky" R&D, product design, product engineering, and process engineering. [Subsidiary A] contracts with its affiliates located in [Country B, Country C, and Country D] to perform R&D services on its behalf. With the exception of certain technology owned by [MNE Entities], [Subsidiary A] owns all intellectual property related to [Products].

[Subsidiary A] contracts with the following entities to perform R&D services on its behalf:

- [Subsidiary B, Country B]
- [Subsidiary C, Country C]
- [Subsidiary D, Country D]

[Subsidiary A] directly reimburses the contract R&D entities for the services provided. In compensation for its R&D service activities, [Subsidiary A] pays the entities a cost-plus mark-up according to their respective R&D arrangements.

The primary functions performed by the contract R&D entities are R&D of [Products] and manufacturing processes. [Subsidiary A] incurs a significant portion of the risk associated with the R&D services. The following is a description of the functions and risks borne by each R&D entity.

[Subsidiary B]

[Subsidiary B] performs contract software R&D services for [Subsidiary A]. [Subsidiary B] specializes in [lengthy Products description and description of industry use]. The scope of development services rendered by [Subsidiary B] includes the following:

- Conceive and propose the development of [detailed description of Products] relating to the [Technology and description of technology] of [Subsidiary A], including estimating time and complexity of such development;
- Analyze competitive products, evaluate costs and benefits of competitive or alternative products, and report its findings;
- Design, develop, and produce enhanced or new [Products] with respect to [Technology] of [Subsidiary A]; and
- Provide such other development services and other administrative support services as [Subsidiary A] may request from time to time.

In return for the R&D services provided, [Subsidiary A] reimburses [Subsidiary B] for the direct and indirect costs it incurs in its provision of R&D services, plus an [XX Percent] mark-up.

Appendix C
Table C.1 Distribution of R&D Subsidiaries

	Proportion of Total		Broadband Introduction Year		Proportion of Total		Broadband Introduction Year
	Headquarters- Controlled	Subsidiary- Controlled			Headquarters- Controlled	Subsidiary- Controlled	
Argentina	0.00	0.51	2007	Luxembourg	0.00	0.03	2004
Australia	2.05	1.84	2004	Malaysia	0.46	0.38	2009
Austria	0.36	0.99	2002	Mexico	1.50	1.36	2008
Belgium	1.68	2.59	2002	Netherlands	1.82	2.86	2002
Brazil	1.36	1.02	2008	New Zealand	0.64	0.85	2005
Canada	3.37	2.73	2001	Norway	1.50	0.82	2003
Chile	0.82	0.51	2006	Peru	0.14	0.20	2013
China	5.09	1.50	2008	Philippines	0.00	0.24	.
Colombia	0.59	0.44	2010	Poland	1.36	1.64	2006
Croatia	0.32	0.17	2006	Portugal	0.73	0.92	2004
Czech Republic	0.46	0.78	2005	Romania	0.14	0.17	2007
Denmark	1.09	0.99	2002	Russian Federation	0.50	1.06	2008
Ecuador	0.00	0.14	2012	Singapore	1.00	1.60	2002
Egypt	0.00	0.10	.	Slovakia	0.00	0.07	2006
Estonia	0.36	0.38	2003	Slovenia	0.00	0.20	2004
Finland	1.68	1.23	2002	South Africa	0.59	0.85	2015
France	6.55	4.40	2003	South Korea	2.77	2.05	2000
Germany	3.96	6.34	2003	Spain	0.55	1.74	2003
Greece	1.36	1.47	2007	Sweden	2.50	2.22	2001
Hong Kong	3.87	2.83	2000	Switzerland	1.68	2.25	2002
Hungary	0.64	0.95	2005	Taiwan	2.50	0.95	.
India	3.59	0.95	.	Thailand	0.36	0.58	2011
Indonesia	0.00	0.10	.	Turkey	0.50	0.68	2007
Ireland	1.41	1.26	2005	United Kingdom	11.64	13.53	2003
Israel	0.96	0.75	2003	United States of America	19.55	22.15	2002
Italy	2.32	3.24	2004	Venezuela	0.14	0.03	2010
Japan	3.55	2.35	2002	Total	100.00	100.00	

Notes: This table contains the percentage of R&D subsidiaries controlled by headquarters and subsidiary MNE entities 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.

Table C.2 Propensity Score Balancing Test

Variable	Unmatched	Mean		% reduced		t-test		V(T)/
	Matched	Treated	Control	% bias	bias	t	p>t	V(C)
Subsidiary Initial Patent Stock	U	0.283	0.347	-9.7		-1.21	0.226	0.68*
	M	0.317	0.366	-7.5	22.9	-0.59	0.553	0.85
Subsidiary Innovation Quantity	U	0.293	0.349	-7.4		-0.92	0.358	0.66*
	M	0.352	0.412	-7.8	-6.1	-0.57	0.568	0.75
Subsidiary Innovation Quality	U	0.442	0.540	-8.9		-1.11	0.268	0.66*
	M	0.510	0.619	-9.9	-12	-0.76	0.450	0.69*
Subsidiary Innovation Market Value	U	0.272	0.499	-19.2		-2.41	0.016	0.34*
	M	0.316	0.377	-5.2	73	-0.46	0.649	0.61*
Subsidiary Knowledge Flows from Control Entity	U	0.135	0.265	-14.4		-1.82	0.070	0.24*
	M	0.214	0.258	-4.8	66.5	-0.41	0.680	0.45*
Subsidiary Co-Inventions	U	0.261	0.335	-10.1		-1.26	0.207	0.63*
	M	0.334	0.380	-6.2	38.8	-0.46	0.649	0.8
Subsidiary Sole Inventions	U	0.057	0.094	-11.9		-1.49	0.137	0.44*
	M	0.070	0.126	-17.8	-49.8	-1.28	0.201	0.43*
Subsidiary Innovation Scope	U	0.160	0.151	2.8		0.35	0.725	1.03
	M	0.148	0.177	-8.7	-209.3	-0.72	0.471	0.78
Subsidiary Ln R&D	U	1.490	1.843	-16.5		-2.07	0.039	0.40*
	M	1.391	1.456	-3.1	81.4	-0.31	0.753	0.78
Subsidiary Role	U	1.700	1.496	29.7		3.69	0.000	1.08
	M	1.685	1.615	10.2	65.6	0.82	0.415	0.85
Subsidiary Number of Control Relationships	U	1.423	1.473	-4.8		-0.61	0.543	0.20*
	M	1.479	1.387	8.7	-81.1	0.89	0.376	0.35*
MNE Size	U	14.055	16.503	-128.9		-16.1	0.000	0.73*
	M	15.063	15.486	-22.3	82.7	-1.71	0.089	0.31*
MNE Diversification	U	0.467	0.831	-67.2		-8.38	0.000	0.85
	M	0.658	0.642	2.9	95.6	0.25	0.805	0.82
MNE Stock Compensation Expense	U	6.985	6.561	8		0.99	0.320	0.73*
	M	6.985	6.668	6	25.1	0.52	0.604	0.88
Host-Country Revealed Technological Advantage	U	0.812	0.871	-11.4		-1.43	0.154	0.89
	M	0.856	0.858	-0.3	97	-0.03	0.979	0.93
Host-Country Industry Market Concentration	U	0.481	0.484	-4.3		-0.54	0.593	0.67*
	M	0.491	0.493	-2.2	49.2	-0.26	0.794	0.94

Notes. Variables are the pre-treatment mean values.

Table C.3 Results for Different Thresholds of Host-Country Broadband Introduction

	Innovation Quantity	Innovation Quality	Innovation Market Value	Co-Invention	Innovation Scope
Thresholds	(1)	(2)	(3)	(4)	(5)
Three Percent	-0.142 (0.076) [0.062]	-0.341 (0.166) [0.041]	0.060 (0.137) [0.661]	-0.113 (0.073) [0.125]	-0.074 (0.056) [0.189]
Five Percent	-0.206 (0.062) [0.001]	-0.364 (0.138) [0.009]	-0.451 (0.170) [0.008]	-0.194 (0.060) [0.001]	-0.123 (0.059) [0.038]
Seven Percent	-0.222 (0.074) [0.003]	-0.381 (0.156) [0.015]	-0.276 (0.153) [0.072]	-0.212 (0.071) [0.003]	-0.113 (0.060) [0.060]
Ten Percent	-0.182 (0.067) [0.007]	-0.247 (0.130) [0.058]	-0.361 (0.159) [0.024]	-0.183 (0.063) [0.004]	-0.153 (0.061) [0.012]

Notes. Coefficients to the triple differences interaction term of headquarters-controlled*post broadband introduction for the full models with time varying country, MNE, and subsidiary controls (Models 6, 12, and 18 of Table 2). Co-invention and innovation scope are similarly estimated on the full models with time varying country, MNE, and subsidiary controls. 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. All tests are two-tailed.

Table C.4 Placebo Tests

	One-Year Lead (1)	Two-Year Lead (2)	Three-Year Lead (3)
<u>Innovation Quantity</u>			
Post-Broadband Introduction	0.091 (0.068) [0.182]	0.060 (0.175) [0.733]	-0.095 (0.190) [0.619]
Headquarters-Controlled* Post-Broadband Introduction	-0.065 (0.090) [0.474]	-0.069 (0.218) [0.751]	0.197 (0.214) [0.359]
<u>Innovation Quality</u>			
Post-Broadband Introduction	-0.033 (0.111) [0.769]	-0.018 (0.378) [0.962]	-0.235 (0.346) [0.497]
Headquarters-Controlled* Post-Broadband Introduction	0.064 (0.122) [0.599]	-0.130 (0.390) [0.740]	0.198 (0.361) [0.585]
<u>Innovation Market Value</u>			
Post-Broadband Introduction	-0.151 (0.194) [0.437]	-0.041 (0.552) [0.940]	-0.847 (0.719) [0.240]
Headquarters-Controlled* Post-Broadband Introduction	0.109 (0.186) [0.558]	-0.293 (0.552) [0.596]	0.579 (0.654) [0.377]

Notes. This table contains the coefficients to the leading Post-Broadband Introduction main term and leading interaction term of Headquarters-Controlled*Post Broadband Introduction. The panels Innovation Quantity, Innovation Quality, and Innovation Market Value indicate the dependent variable used in the triple difference analysis. The leads were estimated for the baseline models in Table 2 containing country-level and MNE-level time varying controls. The Columns indicate one-year, two year, and three-year leads for Post-Broadband Introduction and Headquarters-Controlled*Post-Broadband Introduction. 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. All tests are two-tailed.

Table C.5 The Effect of Broadband on Innovation Quantity by Level of R&D Centralization

	R&D Centralization			
	Full Sample		Matched Sample	
	High	Low	High	Low
	(1)	(2)	(3)	(4)
Post-Broadband Introduction	0.330 (0.155) [0.034]	0.178 (0.045) [0.000]	-0.033 (0.146) [0.823]	0.119 (0.056) [0.034]
Headquarters-Controlled* Post-Broadband Introduction	-0.327 (0.151) [0.031]	-0.113 (0.064) [0.076]	0.060 (0.153) [0.695]	-0.073 (0.074) [0.329]
Country and MNE Controls	Yes	Yes	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Headquarters-Controlled-Year Fixed Effects	Yes	Yes	Yes	Yes
Number of Observations	1652	1691	645	665
Number of Clusters	401	463	116	166
R-squared	0.059	0.095	0.180	0.122

Notes. Sample is split based on the median value of the proportion of total MNE R&D subsidiaries controlled by headquarters. The dependent variable is innovation quantity calculated as the natural log of one plus the total number of patents invented by R&D subsidiary in the given year. Post-Broadband Introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for both the R&D subsidiary-country and the controlling entity country. Headquarters-Controlled*Post-Broadband Introduction reflects the interaction term of the binary indicator for headquarters-controlled R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-controlled R&D subsidiary is 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. All tests are two-tailed.

Table C.6 The Effect of Broadband on R&D Expenditures

	R&D Expenditures			
	Full Sample		Matched Sample	
	(1)	(2)	(3)	(4)
Post-Broadband Introduction	0.293 (0.119) [0.014]	0.195 (0.130) [0.136]	0.236 (0.156) [0.130]	0.254 (0.164) [0.123]
Headquarters-Controlled* Post-Broadband Introduction	-0.175 (0.153) [0.255]	-0.077 (0.166) [0.642]	-0.087 (0.175) [0.621]	-0.126 (0.180) [0.484]
Country and MNE Controls	No	Yes	No	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Headquarters-Controlled-Year Fixed Effects	Yes	Yes	Yes	Yes
Number of Observations	2345	1952	942	902
Number of Clusters	688	591	248	248
R-squared	0.060	0.062	0.088	0.116

Notes. The dependent variable is the natural log of subsidiary R&D expenditures. Post-broadband introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for both the R&D subsidiary-country and the controlling entity country. Headquarters-controlled*Post-broadband introduction reflects the interaction term of the binary indicator for headquarters-controlled R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-controlled R&D subsidiary is 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. All tests are two-tailed.