The Comparative Impact of Headquarters and Subsidiaries in Managing R&D

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Abstract

We investigate the conditions and mechanisms through which R&D subsidiaries generate larger increases in innovation when managed by headquarters versus another subsidiary, as communication technology reduces the costs of overseeing geographically dispersed R&D. We use confidential intra-firm data on the management of 1,004 R&D subsidiaries across 78 multinational enterprises (MNEs) operating in 53 countries from 1997 to 2011. Exploiting the staggered country-level introduction of broadband technology as a reduction in communication costs, we implement difference-in-differences and triple difference-in-differences specifications to investigate whether the effect of broadband on the innovation output of R&D subsidiaries depends on the type of managing entity (headquarters or managing subsidiary). We find that while R&D subsidiaries managed by headquarters are associated with more patents before broadband, after broadband introduction those managed by subsidiaries exhibit significantly larger increases in innovation output, quality, and market value. The managing entity's access to broadband appears to be a necessary condition for these results to be significant. Exploring the underlying mechanisms, we find evidence that reduced communication costs disproportionately benefit managing subsidiaries over headquarters, enhancing their knowledge sharing and monitoring of R&D subsidiaries. Contrary to the notion that communication technologies enhance headquarters' ability to manage R&D across the firm and reduce the proximity advantages of managing subsidiaries, the results suggest that these technologies increase the strategic benefits of having managing subsidiaries oversee R&D. Taken together, this study provides a foundation for developing and refining theory that reflects the complexity of innovation management within MNEs.

Keywords: Firm innovation, R&D management, multinational enterprises, communication technology, broadband

JEL: F23, D83, O32, O34

1. Introduction

A critical yet understudied decision for multinational enterprises (MNEs) is whether to place R&D subsidiaries under the control of headquarters (HQ) or managing subsidiaries (MS).[1] This decision can have substantial consequences for MNE innovation since the managing entity is responsible for essential factors, including sharing knowledge, funding R&D projects, and monitoring the innovation process (Aghion and Tirole 1994, Berry 2015, Manso 2011, Roth and Morrison 1992), as depicted in Figure 1. The role of HQ has been extensively studied, with the HQ-centric perspective highlighting its parenting advantage for providing substantial resources, including access to the MNE's knowledge base and financial resources, to foster R&D subsidiary innovation (Glaeser et al. 2022, Hymer 1960, Nell and Ambos 2013). In contrast, empirical evaluation of MS remains scarce. Studies suggest that MNEs often delegate management to MS to reduce communication friction with geographically dispersed R&D subsidiaries (Gumpert et al. 2022). MS's proximity to R&D subsidiaries and regional hubs of expertise can improve monitoring and access to knowledge (Birkinshaw et al. 2006). However, the HQ-centric view of its superiority in managing R&D has yet to be systematically compared with the potential innovation advantages of vertical subsidiary-to-subsidiary relationships within MNEs. Consequently, the conditions under which R&D subsidiaries generate more innovation under the management of HQ or MS remain unclear.

---Insert Figure 1 here---

This gap in the literature is notable for two reasons. First, MS have become widespread across firms and countries (Ambos et al. 2020, Nell et al. 2017, Teodorescu et al. 2022, Verbeke and Yuan 2018, Zhou 2015). In our sample, MS manage over 70% of the R&D subsidiaries. Second, radical advancements in communication technologies over the past two decades may have altered the relative effectiveness of HQ and MS in fostering R&D subsidiary innovation. For example, the introduction of broadband technology has enabled managing entities to transfer and receive data up to 20 times faster than dial-up and to engage in simultaneous two-way communication, significantly reducing the need for travel and slower communication methods (OECD 2015). These advancements might have a substitution effect on MS' role in mitigating communication frictions, reducing its advantages relative to HQ. Alternatively, they might enable MS to match HQ's capabilities in gathering and sharing knowledge with R&D subsidiaries.

Extant work lacks a clear theoretical prior to predict which effect will persist. It is also likely that multiple mechanisms operate simultaneously to influence this relationship. This study, therefore, aims to

[1] Managing subsidiaries are often termed regional or second headquarters, subsidiaries with strategic mandates, and/or intermediate supervisory units (Birkinshaw et al. 2006, Gillmore et al. 2023, Zhou 2015). They are a separate subsidiary from the subsidiary being managed.

abductively investigate the relative innovativeness of HQ and MS-managed R&D subsidiaries and the conditions and mechanisms through which R&D subsidiaries achieve greater increases in innovation output under MS compared to HQ, in the context of a technologically driven reduction in communication costs. In doing so, our goal is to generate robust empirical evidence that can inform future theoretical models exploring the management of innovation within MNEs.

This research goal faces three important empirical challenges. First, the management of innovation within firms is notoriously difficult to observe (Aghion et al. 2014). Prior work has relied on proxies such as patent assignments and surveys, which have substantial limitations. Patent assignments do not specify when R&D subsidiaries are managed by other subsidiaries and involve legal confounders.[2] Survey data frequently limit the researcher to cross-sectional estimates, which suffer from endogeneity concerns. This is an important limitation given the second empirical challenge, where the assignment of management over R&D subsidiaries is likely endogenous to innovation productivity. Sorting concerns arise because HQ may choose which R&D subsidiaries to manage based on their perceived innovation productivity. Similarly, MNEs may match R&D subsidiaries with managing entities that can better provide resources or share certain characteristics, such as language. Third, the adoption of communication technologies may be endogenous to both the type of managing entity and innovation output.

We address these challenges in several ways. We leverage confidential access to the transfer-pricing reports of 78 MNEs and their managed 1,004 R&D subsidiaries worldwide from 1997 to 2011 to accurately identify managing-managed entity relationships across time and firms. Three features of these data allow us to effectively document the management structure for these companies. First, by international regulations, transfer pricing reports must identify and describe the entities within the firm that manage R&D subsidiaries (e.g., OECD, 2017, IRS Treas. Reg. §1.482).[3] Second, each report includes information about the intra-firm activities for at least three years, allowing us to account for organizational and institutional changes. Third, the information in transfer-pricing reports is strongly reliable. These reports are audited and used in court cases. Inaccurate information can result in stiff penalties and criminal charges (EY 2013).

We then exploit the staggered introduction of broadband technology at the country level as a radical reduction in communication costs. This technology facilitates real-time interaction and rapid dissemination of research resources and findings, enhancing the ability to manage R&D subsidiaries (Akerman et al. 2015). Due to its substantial productivity gains and low implementation costs, the adoption of broadband

[2] The legal assignment of patents is conceptually distinct from managing R&D. MNEs strategically choose which MNE entity to assign a patent based on legal requirements for local presence for patent defense, tax requirements for patent boxes, and the benefits of centralizing patent protection activities into one entity, amongst other factors.
[3] Country governments mandate the reporting of this information, which must follow international standards.

by MNEs was primarily driven by its exogenous availability. Once introduced, the technology diffused rapidly across firms (Bertschek et al. 2013, Ericsson et al. 2013).

Our empirical strategy begins by estimating the pre-broadband correlation between the type of managing entity and the quantity of filed successful patent applications invented by the R&D subsidiary (i.e., innovation output). This step provides a baseline understanding of the innovativeness of R&D subsidiaries managed by HQ compared to those managed by MS. To help mitigate potential systematic differences in R&D subsidiaries by managing entity type, we match subsidiaries on a vector of variables that may affect the assignment to HQ versus MS, as informed by research on MNE innovation management. These variables account for the subsidiary role and MNE- and host-country-industry factors, including regional expertise and geographic and cultural distances between the managing and the managed entities.

Next, we investigate the correlation between reduced communication costs and R&D subsidiary innovation. Using an intention-to-treat difference-in-differences (DD) design, we compare the change in innovation output before and after broadband introduction for the treatment group (subsidiaries with broadband access) against the change in innovation for the control group (those without broadband access at that time). Since communication technologies require both parties to have access, we code broadband introduction as a dyadic measure based on its rollout in both the R&D subsidiary and managing entity locations. We later assess whether the effect persists when only the R&D subsidiary has broadband access.

We then explore whether the effect of broadband on R&D subsidiary innovation varies by the type of managing entity using a staggered triple difference-in-differences estimator (DDD). In practical terms, this approach involves three steps. First, we calculate the change in innovation output for HQ-managed R&D subsidiaries before and after broadband introduction and compare it to the change in innovation for HQ-managed subsidiaries that have not yet had broadband introduced at that point in time. Second, we perform the same calculation for R&D subsidiaries managed by MS. Finally, we subtract the second difference (MS-managed subsidiaries) from the first difference (HQ-managed subsidiaries) and assess its statistical significance. We also run the DDD specifications on a propensity-score matched sample.

A natural concern for the analysis is the potential for new communication technologies to prompt changes in the management structure (Aghion et al. 2014, Dessein 2002). However, changing the managing entity of an R&D subsidiary is costly and typically takes years to implement (Bloom et al. 2012, Bresnahan et al. 2002). In our data, only 79 subsidiaries changed their managing entity during or after the introduction of broadband, accounting for 155 subsidiary-year observations. We exclude these observations to account for this confounder.[4] In essence, the analysis holds constant the structure of innovation management.

[4] The results remain robust when we include these observations. Since the sample of changes is small and the change in managing entity is a different research question, we do not analyze the changes separately.

Two central findings emerge. First, before the introduction of broadband, R&D subsidiaries managed by HQ, on average, were associated with a larger number of patents produced compared to similar R&D subsidiaries managed by MS. Second, while broadband introduction is associated with an increase in R&D subsidiary innovation output on average, this result is predominantly driven by MS-managed subsidiaries. After the introduction of broadband, MS-managed R&D subsidiaries observed an increase of 24.7% in the number of patents produced, which is 33.6% larger than the change among HQ-managed R&D subsidiaries. In fact, for HQ-managed R&D subsidiaries, the average post-broadband change in patent quantity is not statistically different from zero at conventional levels (p-value>0.10).

Although these results generalize across countries, broadband coverage may vary substantially within countries (Atkinson et al. 2009, Mowery and Simcoe 2002). This raises the risk of overestimating the effect of broadband on innovation. To address this concern, we gather U.S. data on broadband availability at the zip-code level and conduct a within-U.S. staggered DDD regression following the same rationale as our main analysis. The results are consistent with the baseline analysis: MS-managed R&D subsidiaries have a significantly larger increase in innovation output after broadband introduction than HQ-managed.

We explore conditions affecting broadband as a communication channel. We first investigate whether broadband has localized direct effects on the R&D subsidiary that sufficiently explains its increase in innovation. The analysis shows no significant results when only the R&D subsidiary has broadband access, suggesting that the managing entity's access to broadband is a necessary condition for the estimated effect of broadband on R&D subsidiary innovation to be observable.

The next condition we explored is the argument that broadband substantially reduces the costs of remote communication (Bertschek et al. 2013, Bloom et al. 2014). If so, we would expect the effect of broadband on innovation to increase with the geographical distance (Glaeser et al. 2022). We find that the estimated effects of broadband are more pronounced for subsidiaries located farther than the median distance from their managing entities than those located closer. However, these differences are not statistically significant, suggesting that the management advantages of MS are not solely due to their physical proximity to subsidiaries, which has often been cited as the key reason for their adoption by firms (Monteiro et al. 2008).

We employ several robustness checks, including using placebo years for broadband introduction, different thresholds for broadband penetration, and testing heterogeneous treatment effects in the staggered triple difference-in-differences design. We also use innovation quality and market value as alternative dependent variables. Across these tests, we find consistent support that broadband introduction is associated with a significantly greater increase in MS-managed R&D subsidiary innovation than HQ-managed.

Our next step is to explore the potential mechanisms behind these results. Building on the innovation management literature, we identify three primary channels through which managing entities influence R&D subsidiary innovation: knowledge sharing, R&D funding, and monitoring (Baaij and Slangen 2013, Berry

2015, Ghoshal and Bartlett 1988, Nobel and Birkinshaw 1998). If these mechanisms drive the results, we should observe more pronounced post-broadband improvements in variables related to these channels for MS-managed than for HQ-managed R&D subsidiaries.

First, broadband can facilitate the MS sharing more and better knowledge with the R&D subsidiary (Forman and van Zeebroeck 2019). This is especially important for exchanging tacit knowledge for new inventions, which is often context-dependent and requires rich interactions (Singh 2008). We find strong evidence supporting this mechanism. MS-managed R&D subsidiaries experience a 17.4% larger post-broadband increase in knowledge flows, measured by the R&D subsidiary's backward citations to the managing entity's prior art, compared to HQ-managed subsidiaries. A potential explanation is that broadband enables MS to leverage their contextual intelligence to share relevant knowledge that complements the invention process within these subsidiaries.

Second, broadband can reduce communication frictions for R&D subsidiaries to propose new projects and alleviate information asymmetries for managing entities to approve and fund them. It can also enable real-time financial tools such as collaborative budgeting and instant fund transfers that can help the managing entity improve responsiveness and precision in allocating resources (Akerman et al. 2015, Bertschek et al. 2013). These factors can lead to an overall increase in the number of projects proposed and adequately funded, thereby enhancing the innovation output of subsidiaries (Hall and Lerner 2010). However, the analysis does not provide evidence of this channel, as the post-broadband differences in R&D funding between MS- and HQ-managed subsidiaries are not significant.

Finally, broadband can improve monitoring by allowing the managing entity to provide more thorough and timely reviews and feedback on R&D activities and make necessary adjustments to projects in real-time (Manso 2011). Although we have no direct measure of monitoring in our dataset, following prior research that suggests that high-quality monitoring is associated with greater innovation productivity (Aghion et al. 2013, Ahuja et al. 2008) and communication technologies enhance the capacity of managing entities to monitor more subsidiaries (Bloom et al. 2014, Garicano 2000), we find suggestive evidence of this channel. MS-managed R&D subsidiaries have, on average, a 29.0% larger increase in post-broadband innovation productivity than HQ-managed R&D subsidiaries and the estimated effect is more pronounced for managing entities with a high span of control, i.e., those that oversee more subsidiaries than the median.

This study contributes to three key research areas. First, it contributes to the literature on MNE innovation management (Berry 2015, Glaeser et al. 2022, Nobel and Birkinshaw 1998) by providing the first large-scale empirical investigation comparing HQ- and MS-managed R&D subsidiary innovation output. Existing research has provided valuable insights into the benefits of delegating control over R&D subsidiaries to MS primarily through theory or qualitative case studies (e.g., Birkinshaw et al. 2006, Lunnan and Zhao 2014, Teodorescu et al. 2022). The findings provide a counterpoint to the HQ-centric view of

innovation management and suggest that advances in communication technologies are shifting the relative advantages of HQ and MS in managing R&D. We find evidence that MS facilitate greater increases in knowledge flows and monitoring compared to HQ, thereby positively influencing R&D productivity.

These findings are counterintuitive to existing theoretical predictions. On the one hand, reduced communication costs should benefit HQ by improving its ability to leverage its parenting advantages across more units (Bloom et al. 2014). On the other hand, the introduction of broadband should diminish the advantage of proximity to R&D subsidiaries—a characteristic attributed to MS in mitigating communication frictions in R&D management (Gumpert et al. 2022). Yet, we find that broadband predominantly benefits MS-managed subsidiaries.

Different arguments may rationalize our counterintuitive findings without implying that HQ delivers subpar management, which has not been an outcome of our analysis. For instance, MNEs may have already optimized R&D productivity under HQ control, making additional innovation gains from broadband less noticeable for HQ-managed subsidiaries. Alternatively, MS' deeper understanding of regional R&D landscapes and access to locational hubs of expertise (Birkinshaw et al. 2006) may enable them to use communication technologies more strategically, gathering relevant data and tailoring it into actionable knowledge that better aligns with their R&D subsidiaries' specific needs and potential. These hypotheses point to promising avenues for further exploration.

Additionally, this study extends research on the (de)centralizing R&D management and its performance consequences (Asakawa 2001, Eklund 2022). Traditionally, studies have simplified firms' choices to centralization in HQ or self-managed subsidiaries, overlooking the vital role that intermediary supervisory units play for the MNE. The significant post-broadband increases in innovation seen under MS management underscore the theoretical and managerial relevance of studying the implications of vertical subsidiary-to-subsidiary authority relationships for MNE innovation.

Finally, the findings connect with research on the impact of communication technologies on firm performance, focusing on the long-standing puzzle of why firms often fail to benefit from these technologies (Bloom et al. 2012, Schreyer 2000, Stiroh 2002). The results suggest that organizational structure, particularly the delegation of control over R&D units to MS versus HQ, may explain some of the heterogeneity in the productivity gains from communication technologies. HQs, particularly those with extensive spans of control, do not seem to leverage broadband to fully capitalize on their organizational centrality for transferring knowledge and funding to R&D subsidiaries. This does not imply that HQ does not benefit from this technology. HQ may use communication technologies for a broader range of processes, whose impact may not be directly observable in innovation outcomes.

In sum, this study underscores the often-underrated role of MS in managing geographically dispersed R&D. It paves the way for future theoretical predictions about when and why HQ or MS hold an advantage

in fostering MNE innovation. The rest of this paper is organized as follows: Section 2 describes the data and the introduction of broadband as a reduction in communication costs. Section 3 analyzes the correlation between the type of managing entity and R&D subsidiary innovation output. It then investigates the differential effect of broadband introduction on R&D subsidiary innovation by managing entity type, explores the conditions influencing the estimated broadband effect, and assesses potential mechanisms underlying these results. Section 4 addresses specification tests, alternative explanations, and robustness checks. Section 5 concludes with a discussion of the theoretical and managerial implications of the findings.

2. Data and Setting

2.1. The Management of R&D Subsidiaries

When MNEs allocate control rights over R&D subsidiaries to either HQ or MS, they make a decision that has far-reaching implications for the productivity and success of the firm's innovation efforts. The managing entity is responsible for the most important strategic decisions and factors for innovation, such as R&D project approval and funding, knowledge sharing, and monitoring (Aghion and Tirole 1994, Berry 2015, Manso 2011, Roth and Morrison 1992). Both MS and HQ are incentivized to foster innovation in their R&D subsidiaries, as control rights grant them ownership of the resulting innovations (IRS Treas. Reg. §1.482, OECD 2017). Thus, they capture the returns or bear the losses from successful or failed R&D efforts (Magelssen 2020). In exchange, the managing entity must compensate the R&D subsidiary for its work (IRS Treas. Reg. §1.482, OECD 2017). The relationship between a managing entity and an R&D subsidiary is typically long-lasting. Once assigned, the managing entity's authority over the subsidiary is difficult to revoke (Cuervo-Cazurra et al. 2019, Magelssen 2020).

International regulations mandate that firms document these arrangements and intra-firm transactions in transfer pricing reports. These reports ensure that intra-firm transactions, such as the exchange of goods, services, or intellectual property, are conducted at arm's length—reflecting market conditions as if the entities were unrelated. Transfer pricing reports provide transparency in the allocation of income, expenses, and risks among MNE entities across jurisdictions, helping to prevent profit shifting and ensure compliance with tax regulations (OECD 2017). Tax authorities use these reports to verify that managing entities and R&D subsidiaries in their jurisdictions receive the appropriate income and impose substantial penalties for non-compliance (EY 2013).

Transfer pricing reports offer detailed operational information on managing-managed entity relationships, activities, rights, and associated profits or losses. These details are verified through written contracts (Appendix A provides a sample excerpt), payment and transaction flows, and interviews with managers to clarify roles, responsibilities, and activities (OECD 2017).

For this study, we construct a panel on innovation management using the transfer pricing reports for

the 102 MNEs and their 1,004 R&D from 1997 to 2011. We obtained access to these reports through a confidentiality agreement with a consulting firm. The dataset contains the data from all 102 MNEs that the consulting firm had information in accordance with company agreements for provision under the confidentiality agreement at the time of data collection. Strict confidentiality was maintained in coding and handling the data, and this paper reports aggregate statistics to not identify any firm in the sample. This data was essential for our research goal. The lack of empirical research on MS R&D management is largely because identifying the managing entities of R&D subsidiaries is not feasible through public or purchased databases.

The MNEs in the dataset are primarily in manufacturing industries, with some in the retail and service sectors. Approximately 78% are headquartered in North America, 19% in Europe, and the rest in Asia. Given our focus, we limit the sample to 78 MNEs with subsidiary-invented patents.[5]

To assess the representativeness of the MNEs in our sample, we collect data for the sample period from the Orbis database on the 2,000 largest MNEs worldwide, based on Forbes Global 2000 rankings by 2011 revenue. After removing MNEs in agriculture, mining, banking, and public administration because these industries generally do not innovate and are not in our focal sample, the MNEs in our sample show no significant differences in firm size ($p=0.19$) and R&D intensity (for firms that report R&D expenditures, $p=0.13$) compared to the Orbis MNEs ranked 1,150-2,000. Thus, our sample represents relatively large MNEs, though not the very largest companies globally.

We also compare our sample to a random sample of Fortune 1000 firms from Cho and Pucik (2005). At the MNE-level, we find that the MNEs in our sample are not statistically different in total assets ($p=0.87$) and total revenue ($p=0.44$). Finally, we assess whether our sample is comparable to Berry (2014), who uses perhaps one of the best datasets on MNE innovation over our sample period. Her dataset contains information on the patenting of the foreign subsidiaries of U.S. MNEs from the Bureau of Economic Analysis, which we view as an important dimension in assessing the generalizability of the MNEs in our sample. We find no significant differences in MNE size ($p=0.17$), the proportion of foreign subsidiaries performing R&D (16.9% in our data vs. 18.2% in Berry (2014)), or in the average annual patents per MNE ($p=0.29$).

Importantly, qualitative information from our dataset enables us to accurately identify managing entity-R&D subsidiary relationships. We read each transfer pricing report to identify the entities that managed the R&D activities of subsidiaries across time. We create indicators for the two types of units that can control subsidiaries, HQ and/or MS. We code an R&D subsidiary B as managed by subsidiary A (or HQ A) at time t if the report documented that subsidiary B was under the direction or control of subsidiary

[5] Of note, this study focuses on the management of R&D activities, rather than the reasons MNEs choose specific R&D locations. Thus, the analysis is conditional on the MNE assigning R&D activities to the subsidiary.

A, or contracted to perform R&D on behalf of subsidiary A (see Appendix A for an example excerpt of a contract). *Headquarters-Managed* equals 1 if HQ manages the R&D subsidiary, and 0 otherwise. Appendix B provides a redacted sample from a representative transfer pricing report, where subsidiary A is the managing entity and subsidiary B is the R&D subsidiary.

The 1,004 R&D subsidiaries assigned to a managing entity have 4,395 subsidiary-year observations. Of these subsidiaries, 54.7% are managed by HQ and 73.2% by an MS. The sum exceeds 100% as 269 subsidiaries perform projects for multiple managing entities, with 50.5% of these managed by both HQ and MS. A total of 677 subsidiaries are under a single managing entity, with 50.7% managed by HQ and 49.3% by MS.

A total of 96 R&D subsidiaries experienced a change in their managing entity during the sample window, with 79 of these occurring in or after the year of broadband introduction in their respective countries. We retain the R&D subsidiary in the sample as long as its management remains unchanged. We exclude 155 subsidiary-year observations for the years during and after the management change to ensure that these changes do not affect the results. The time between broadband introduction and the management change ranges from zero to eight years, with a median and mean of four years. Most changes occurred around the 2008 financial crisis. Seven subsidiaries were dropped from the sample due to the timing of their changes, reducing the sample to 4,240 subsidiary-year observations across 997 subsidiaries.

We also exclude four subsidiaries (16 subsidiary-year observations) that license technologies from another MNE entity to avoid conflating intra-firm management effects with licensing relationships. Consistent with prior research (e.g., Zhou 2015), 47 subsidiaries (215 subsidiary-year observations) with pure tax haven management relationships—where managing entities are located in tax havens without operations—are also excluded. The final sample includes 4,009 subsidiary-year observations for 946 managed R&D subsidiaries.

2.2. The Introduction of Broadband as a Reduction to Communication Costs

To investigate whether advancements in communication technology have affected the relationship between the managing entity type and R&D subsidiary innovation, we focus on the introduction of broadband technology. This empirical setting is ideal for our analysis because broadband has radically reduced communication costs with dispersed operations (OECD 2015). The staggered nature of the introduction of this technology across countries allows us to mitigate, albeit not eliminate, concerns about time-varying institutional factors that could influence subsidiary innovation.

Broadband, defined as high-speed internet access with download speeds of at least 256 Kbit/s, has transformed inter-unit communication by enabling simultaneous two-way data transfers, real-time video

conferencing, and higher-quality, rapid data transfer (Ericsson et al. 2013, Ezell et al. 2009, OECD 2015).[6] Before broadband, firms depended on slower, costlier alternatives (Ericsson et al. 2013). Principally, alternatives such as dial-up internet offered a maximum speed of 56 Kbit/s, which made data-intensive communications, such as video conferencing, practically unfeasible (Ezell et al. 2009). Wide area networks (WANs) could connect offices to mainframe systems, but they were too expensive to lease for most firms (Majumdar 2019). Both WANs and private intranets relied on the country's available infrastructure because the private installation of communications technologies, such as broadband across geographical distances, was prohibitively costly for firms (Majumdar 2019, De Wit 2022). Other alternatives included telephone (including conference calling), messenger services, traditional mail, and in-person visits.

Firms quickly adopted broadband once it became available due to its low implementation costs and potential for significant productivity gains (Antonelli 2002, Bertschek et al. 2013, OECD 2015). Broadband dramatically reduced communication costs by enhancing managing entities' ability to share complex information and tacit knowledge with geographically dispersed units, facilitating real-time interaction, and reducing the need for travel (Bertschek et al. 2013).

Broadband began to be rolled out by telecommunications companies in the early 2000s, generally in urban and industrial centers where MNEs are typically located. Governments drove the installation of broadband infrastructure due to its socioeconomic impacts (OECD 2015). The European Commission, for example, aimed for full broadband coverage in all EU countries by 2013 (OECD 2015). By 2011, broadband had been introduced in 85% of the countries in the sample.

We obtain data on fixed broadband subscriptions from the World Bank's World Development Indicators, which tracks broadband penetration as a percentage of fixed broadband subscriptions in the population, including businesses and residences. Following specialized studies, we set a 5% market penetration rate as the threshold for broadband introduction and use different thresholds in robustness tests to ensure consistency (Ezell et al. 2009, Mack-Smith 2013). Research indicates that, even at low penetration rates, the availability of communication infrastructure can significantly enhance firm productivity (Roller and Waverman 2001). Since communication technologies function when both parties have access (Forman and van Zeebroeck 2019), we code *Post-Broadband Introduction* as a binary indicator set to one starting the year after broadband penetration reaches 5% in the countries of the R&D subsidiary and the managing entity. The mean and median time a country in our sample reaches the broadband threshold is two years.

2.3. Innovation Data

[6] Video conferencing was slow to gain widespread adoption after the introduction of broadband and is therefore more likely to be a factor towards the end of our sample (Tucker 2008).

We measure innovation using patents, a widely recognized and externally validated indicator of technological novelty commonly used in studies of firm innovation (Griliches 1990, Lerner and Seru 2017). Patent data, including inventor locations, assignees, forward and backward citations, and technological classes, are sourced from the United States Patent and Trademark Office (USPTO). Using patent data from a single patent authority is standard practice due to variations among different patent offices (Berry 2014). We chose the USPTO for this study because it consistently reports inventors' addresses throughout our sample period. Other patent offices either did not collect or did not systematically collect inventor locations or only required the identification of one inventor. While USPTO data may introduce a bias towards U.S. subsidiaries, this bias is somewhat alleviated because all MNEs in our dataset have at least one U.S. location, and firms active in the U.S. have a strong incentive to file with the USPTO regardless of invention location. We conduct robustness tests by focusing separately on R&D subsidiaries in and outside the U.S., finding consistent results in both cases.

To construct the innovation panel, we search the USPTO database for all granted patent applications assigned to each MNE or any subsidiary within the MNE group.[7] Our search includes the full legal entity name and variations of the root name, incorporating suffixes such as "Inc.," "Corporation," "A.G.," and "SAS." In cases of ambiguity regarding the corresponding MNE or subsidiary, we verify the assignee address to ensure it corresponds to one of the MNE's known addresses. Our dataset contains 50,934 patents.

We match all the entities of the MNEs in our data to their invented patents based on the inventor's city, state, country, and year of filing, given that the filing date is closer to the invention date than the grant date (Lerner and Seru 2017). For instances with multiple MNE entities in the same city, we match patents based on the overlap in the assignee and MNE entity names. If MNE entities have similar root names, we match based on the technological focus of the entity. For example, if two pharmaceutical subsidiaries conduct R&D on drugs, a patent for an oncological drug is linked to the subsidiary focused on oncological research.

Our dataset includes 29,028 patents with a single inventor, 10,711 patents with multiple inventors from the same MNE entity location, and 11,195 patents with inventors from multiple MNE-entity locations, which we code to each inventing subsidiary.[8]

2.3.1. Dependent Variable. The main dependent variable in our analysis is *Innovation Output*, measured as the natural log of one plus the total number of successful patent applications filed by the R&D subsidiary's inventors each year. In robustness tests, we use two alternative measures. *Innovation Quality* is measured by the total number of forward citations (excluding examiner citations) received from other firms within five years of the subsidiary's granted patent application year. Forward citations are highly

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

[8] We code the variable this way because the focus of this study is on the effect of broadband on the focal R&D subsidiary's innovation. We perform a robustness test with each patent weighted by the number of co-inventing entities and find consistent results (see Appendix D.1).

correlated with an innovation's underlying value and importance (Hall et al. 2005, Lanjouw and Schankerman 2004). To address the mechanical decline in citations towards the end of the patent database (Lerner and Seru 2017), we limit the analysis of innovation quality to patents filed by 2009, ensuring each patent has the same five-year window to receive citations. *Innovation Market Value* is the MNE market-adjusted returns in millions of dollars within three days following a patent's issue date for the patents invented by the focal R&D subsidiary in that year, adjusted to 1982 dollars (Kogan et al. 2017). We obtained this measure from the Kogan database, which covers 61.1% of all patents in our sample.[9] Innovation market value captures the anticipated commercial value of the innovation (Kogan et al. 2017). We use the natural log of one plus the values of innovation quality and market value.

2.4. Other Data

The analyses incorporate control variables for the R&D subsidiary's country-industry revealed technological advantage and market concentration index; MNE size, diversification, and stock compensation; and subsidiary role. We include the subsidiary's R&D expenditure in our mechanism tests. Additionally, we employ a set of supplementary variables for the matched sample and other analyses. Details on these variables, their sources, and their construction are provided in Appendix C.

2.5. Descriptive Statistics and Propensity Score Matched Sample

2.5.1. Broadband Introduction and R&D Subsidiary Innovation by Managing Entity Type. Table 1 details the distribution of R&D subsidiaries by country location and managing entity type. There are 53 countries represented in our data. About 11.6% of HQ-managed subsidiaries and 13.5% of MS-managed subsidiaries are in the U.K. In comparison, 19.6% of HQ-managed and 22.2% of MS-managed subsidiaries are based in the U.S. Broadband technology was introduced in countries between 2000 and 2015, with a median country introduction year of 2004.

Table 2 compares the mean values of key variables for R&D subsidiaries managed by HQ only, MS only, or both. In terms of innovation output, the table shows that before the introduction of broadband, HQ- and MS-managed subsidiaries produced similar quantities of patents. However, HQ-managed subsidiaries slightly outperform MS-managed ones in forward citation count, suggesting better quality or impact of their innovations. In contrast, MS-managed subsidiaries have higher mean innovation market values, which suggests greater expected commercial success or market reception. Following the introduction of broadband, MS-managed subsidiaries exhibit larger average innovation output, quality, and market value compared to those managed by HQ.

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

------Insert Tables 1 and 2 About Here------

2.5.2. Propensity Score Matching for Managing Entity Type. The assignment of R&D subsidiaries to either HQ or MS is not random and could be influenced by several factors, raising concerns about potential endogeneity. Firms may strategically decide whether to place control with HQ or MS based on characteristics such as the subsidiary's location, industry, size, or the firm's broader strategic goals. For example, R&D subsidiaries located in regions with greater innovative capacity might be more likely to be managed by MS to leverage local expertise (Birkinshaw et al. 2006). Similarly, larger or more strategically important subsidiaries might be managed by HQ to ensure direct oversight. These underlying differences could bias the comparison between HQ- and MS-managed subsidiaries and cause misleading conclusions.

To mitigate this concern, we use propensity score matching (PSM). The PSM procedure is one of the most commonly employed matching methodologies (e.g. Dambra and Gustafson 2021, Faccio and O'Brien 2021, Lin et al. 2021). This method allows us to balance the observable characteristics between HQ- and MS-managed subsidiaries by matching them to factors that may influence both the management structure and innovation outcomes. We use two matching vectors and employ nearest-neighbor matching without replacement in both cases. For the baseline OLS analysis detailed below, we use a logit selection model to estimate the propensity of an R&D subsidiary being managed by HQ versus MS. For this, we draw upon research suggesting that MNEs are more likely to delegate control to MS that are geographically and culturally more proximate to the subsidiary, especially for MNEs that are large and diversified (Birkinshaw et al. 2006, Gumpert et al. 2022, Kostova et al. 2016, Teodorescu et al. 2022). Thus, the matching algorithm includes geographical and cultural distance between the managing entity and the R&D subsidiary, whether the managing entity has the same official language as the R&D subsidiary, and the mean pre-broadband value of MNE size, diversification, stock compensation, host-country-industry technological advantage, host-country-industry market concentration, industry, and host-country location. Appendix C has detailed descriptions of the variables used to calculate these constructs. Measures of innovation outcomes are excluded from the matching algorithm in this analysis to understand the correlational differences in subsidiary innovation by managing entity types.

When both HQ and MS manage an R&D subsidiary, we are unable to differentiate the total patents attributable to HQ- versus MS-managed R&D projects. Therefore, we match R&D subsidiaries managed exclusively by either HQ or MS to better isolate the effects of HQ versus MS management.

Table 3a presents baseline OLS balancing tests, with Column 7 showing t-tests for differences between unmatched and matched samples for each variable. The first row reflects the statistical differences between HQ- and MS-managed R&D subsidiaries in the full (unmatched) sample, while the second row shows the differences for the matched sample. The results indicate that, in the unmatched sample, HQ-managed R&D subsidiaries tend to be farther from the managing entity, more likely to share the same official language,

and are typically in smaller firms than MS-managed subsidiaries. The t-tests confirm that the PSM effectively reduces these differences between HQ- and MS-managed R&D subsidiaries.

------Insert Table 3a About Here------

We also apply propensity score matching (PSM) for the DD and DDD specifications to help address the potential systematic differences between HQ- and MS-managed R&D subsidiaries that could influence their post-broadband changes in innovation. To the matching algorithm used for the OLS described above, we incorporate pre-broadband characteristics and roles related to the innovativeness of both the R&D subsidiary and the managing entity: the R&D subsidiary's mean pre-broadband innovation output, market value, R&D expenditures, knowledge flows from the managing entity, as well as the managing entity's innovation output and R&D spending. Of note, our inclusion of host-country location in the matching alleviates concerns about biases from the baseline communication infrastructure and the type of broadband technology (e.g., DSL vs. fiber) across different countries.

Table 3b provides the propensity score balancing test for the DD and DDD estimations. In the unmatched pre-broadband sample, MS-managed R&D subsidiaries are, on average, larger in terms of R&D expenditures and MNE size than HQ-managed subsidiaries. While MS-managed R&D subsidiaries tend to be in more diversified firms, HQ-managed subsidiaries tend to have greater geographical distance from their managing entities. Additionally, these subsidiaries have higher innovation market value, although the difference compared to MS-managed subsidiaries is not statistically significant in the unmatched sample.

The propensity score matching significantly reduces biases across key variables. For example, the bias in innovation market value decreases by 51.5%, while for R&D subsidiary role, it drops by 76.5%. Furthermore, the cultural distance between HQ-managed subsidiaries and managing entities initially has a higher bias of 43.2%, which decreases by 78.9% after matching. The bias in managing entity R&D expenditures drops from 22.4% to 11.8% after matching, while it decreases by 60.1% for geographical distance. Overall, the matching procedure effectively minimizes differences in the pre-treatment characteristics between HQ- and MS-managed R&D subsidiaries, allowing for a more balanced comparison in subsequent analyses. We also present the primary analysis results using the (unmatched) full sample.

------Insert Table 3b About Here------

2.5.3 Other Data Facts. Table 4 provides detailed descriptive statistics for the full sample and matched samples. On average, R&D subsidiaries produce 1.97 patents per year. However, this value is skewed by a few high-output subsidiaries, as evidenced by a standard deviation of 7.55. After matching, the average number of patents drops to 0.36 per year, with a much lower standard deviation of 1.09. This suggests that the matching procedure successfully eliminates extreme outliers and provides a more balanced sample for the analysis. Innovation quality, measured as the number of citations per patent, has a mean of 4.37 in the full sample, which remains consistent in the matched sample. Regarding market value, the mean value of

patents is $43.88 million for the full sample but is reduced to $2.06 million after matching. This decrease likely reflects the exclusion of extremely high-value patents, further confirming the improvement of the matching process in reducing outlier effects.

Subsidiary R&D expenses average around $5.86 million in the full sample, though this figure also varies widely, as indicated by the large standard deviation of $294.26 million. The matched sample shows a reduction in average R&D expenses to $210.7 million, with a corresponding decrease in variance.

On average, managing entities are located 4,837 miles from their R&D subsidiaries, with distances ranging from 9.56 to 19,147 miles. The average distance between managing entities and their R&D subsidiaries in the matched sample remains relatively consistent at 4,372 miles. About 40.9% of R&D subsidiary-managing entity relationships are with countries sharing the same official language in the full sample, while this percentage slightly increases to 43.1% in the matched sample. A total of 160 subsidiaries in our sample (or 16.9%) had knowledge flows greater than 0. The average number of backward citations to managing entities, used as the proxy for knowledge flows, is 0.99 for the full sample, reducing to 0.11 after matching.

Finally, MNEs in our dataset report total revenues of $22.3 billion and stock compensation expenses of $124.1 million on average. To maintain the confidentiality of company-specific data, only aggregated statistics (and not firm-specific minimum and maximum values) are presented for these variables.

------Insert Table 4 About Here------

3. Analysis

3.1. The Association between the Type of Managing Entity and R&D Subsidiary Innovation

We start by assessing the baseline association between the type of managing entity and the R&D subsidiary's innovation output. To achieve this, we employ OLS models with panel random effects on both the pre-broadband full sample and PSM-matched sample, structured as follows:[10]

$$Y_{it} = \beta_0 + \beta_1 HQ_{it} + \beta_2 \mathrm{X}_{it} + \gamma_t + \mu_i + \varepsilon_{it} \quad (1)$$

where Y_{it} is the innovation outcome generated by subsidiary i in year t, HQ_{it} is a binary variable for HQ-managed, X_{it} represents a vector of control variables for the R&D subsidiary, the host-country-industry, and MNE, γ_t denotes year-fixed effects, and μ_i indicates industry fixed effects. Standard errors are clustered by R&D subsidiary.

Table 5 presents the results. We do not find a significant association between HQ management and the patents produced by R&D subsidiaries in the full sample ($p>0.10$). However, after accounting for potential

[10] The Breusch and Pagan Lagrangian multiplier test for random effects was significant ($p<.001$), thereby indicating the presence of random effects and rejecting a pooled OLS model. Because HQ-managed, the independent variable of interest, is constant in our sample, we are unable to employ R&D subsidiary fixed effects in the OLS analysis.

confounders that influence whether HQ or an MS manages a subsidiary with the PSM sample, we find a positive association between HQ management and innovation output. Taking the exponentiated value, a subsidiary managed by HQ is associated with producing an average of 18.6% more patents per year than a similar subsidiary managed by MS ($p<0.046$). After accounting for the subsidiary's R&D expenditures in Column 4, we find that HQ-managed subsidiaries are associated with higher innovation productivity than MS-managed subsidiaries ($p<.044$).

------Insert Table 5 About Here------

3.2. Broadband Introduction and R&D Subsidiary Innovation

Next, we investigate the effect of broadband on R&D subsidiary innovation and whether it differs according to the type of managing entity. Starting with the raw data, Figure 2 presents binscatter plots comparing the innovation output for HQ- and MS-managed subsidiaries across the values of broadband penetration. The plots show that as broadband penetration increases, MS-managed R&D subsidiaries produce more patents, while the innovation output from HQ-managed R&D subsidiaries remains relatively stable.

We use a combination of difference-in-differences (DD) and triple difference-in-differences (DDD) models for our analyses. The DD model estimates changes in innovation output for R&D subsidiaries from the introduction of broadband, i.e., treatment group, compared to the changes in innovation output for R&D subsidiaries that have not yet had broadband introduced at that time, i.e., control group. The DDD model allows us to assess the differences in the effect of broadband on innovation between HQ-managed and MS-managed R&D subsidiaries. We discuss the exponentiated coefficients for a straightforward interpretation.

------Insert Figure 2 About Here------

3.2.1. Estimating the Effect of Broadband on R&D Subsidiary Innovation. We estimate the following specification using the DD model:

$$Y_{it} = \beta_0 + \beta_1 Post\ Broadband_{ct} + \beta_2 X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \quad (2)$$

Here, Y_{it} represents the dependent variable of interest for subsidiary i in year t. The variable *Post-Broadband*$_{ct}$ is the binary indicator for broadband introduction explained in Section 2.2. The vector X_{it} includes control variables for the subsidiary, host-country-industry, and MNE. We add subsidiary, α_i, and year, γ_t, fixed effects.

Table 6, Columns 1 to 5 presents the results for Equation 2. The first column contains the results for the full sample, Columns 2-3 and Columns 4-5 contain the results for the sample of HQ-managed R&D subsidiaries and MS-managed R&D subsidiaries, respectively. After broadband introduction, R&D subsidiaries across the dataset have an average increase of 9.1% in the number of patents produced (Column 1, $p<0.001$) compared to those that did not have broadband introduced at that time.

This result appears to be predominantly associated with MS management. Columns 2 and 3 indicate that post-broadband introduction, HQ-managed R&D subsidiaries do not exhibit substantial changes in

innovation output (p=0.746, Column 3) relative to HQ-managed without broadband. Conversely, the change in innovation output for subsidiaries managed by MS is markedly positive. Column 5, which presents results from the most stringent model, indicates that MS-managed subsidiaries are associated with an average increase of 21.0% in patents after the introduction of broadband (p<0.001) relative to MS-managed without broadband.

3.2.2. Estimating the Effect of Broadband on the Relationship between the Type of Managing Entity and R&D Subsidiary Innovation. The DDD model allows us to further test whether the estimated effects of broadband differ between MS and HQ-managed R&D subsidiaries. The DDD is a modification to the DD specification as follows:

$$Y_{it} = \beta_0 + \beta_1(Headquarters - Managed_{it} \times PostBroadband_{ct}) + \beta_2 PostBroadband_{ct} + \beta_3 X_{it} + \alpha_i + \eta_{it} + \gamma_t + \varepsilon_{it} \quad (3)$$

In addition to the control variables and fixed effects in Equation (2), we include in Equation (3) HQ-managed interacted with year-fixed effects, η_{it}, to isolate the triple differences (Pischke 2005). β_2 captures the change in innovation outcomes for MS-managed R&D subsidiaries in countries with broadband introduction relative to MS-managed R&D subsidiaries without broadband at that time. The main term of interest in the DDD analysis is $Headquarters - Managed_{it} \times PostBroadband_{ct}$. Essentially, its coefficient β_1 identifies the differential effect of broadband for HQ-managed versus MS-managed R&D subsidiaries by accounting for existing differences between them in areas where it has not yet been introduced. Its calculation entails the following procedure:

i) Post-Broadband Difference in Innovation for HQ-Managed R&D Subsidiaries: We first calculate the change in innovation output for HQ-managed R&D subsidiaries before and after the staggered introduction of broadband. We then compare it to the change in innovation output for HQ-managed R&D subsidiaries without broadband introduction at that time.

ii) Post-Broadband Difference in Innovation for MS-Managed R&D Subsidiaries: Similarly, we compute the change in innovation output for MS-managed R&D subsidiaries before and after the staggered introduction of broadband and compare it to the change for MS-managed R&D subsidiaries that have not yet had broadband introduced at that time.

iii) Comparison of Differences: The final step involves comparing these two differences. We subtract the change in innovation output observed in MS-managed subsidiaries in step two from that observed by HQ-managed R&D subsidiaries in step one. The magnitude of β_1 captures the relative significance of the difference between the post-broadband change in HQ- versus MS-managed subsidiary innovation.

The results of the DDD analysis confirm a nuanced effect of broadband that depends on the type of

managing entity. In Table 6 Column 7, the negative coefficient for the interaction between HQ management and broadband introduction indicates that HQ-managed R&D subsidiaries exhibit a significantly lower post-broadband change in the number of patents produced compared to MS-managed subsidiaries. Since the positive post-broadband estimated effect on MS-managed subsidiaries is economically significant, we infer that the DDD coefficient can be interpreted as indicating a 22.3% smaller post-broadband increase among HQ-managed subsidiaries than for those managed by MS ($p<0.001$). Given that we measure the post-broadband change in innovation output, this does not necessarily mean that HQ-managed subsidiaries produce less innovation than those controlled by MS.

The economically important gap in the change in innovation after broadband is more pronounced in the matched sample. As observed in Column 9, which reports the results of the most stringent specification, R&D subsidiaries managed by HQ exhibit a 33.6% smaller post-broadband increase in patents relative to those managed by MS. This result is significant ($p<0.001$), highlighting a stronger differential estimated effect when controlling for pre-broadband characteristics through matching.

------Insert Table 6 About Here------

3.3. Within-Country Differences in the Availability of Broadband

Thus far, we have found evidence that the innovation output of R&D subsidiaries increases following the introduction of broadband using country-level data. However, it is crucial to consider that the actual availability of broadband may vary substantially within countries (Akerman et al. 2015, Prieger 2003). For instance, the greater patent increase observed among MS-managed subsidiaries might be due to HQ-managed subsidiaries being more likely to operate in country regions with no broadband coverage, although the data show that the country has adopted the technology. This variation may bias our findings and lead to erroneous conclusions.

To address this concern, we collect historical data on broadband by U.S. zip code from the Federal Communications Commission (FCC), which tracks the number of broadband providers per zip code during our sample period.[11] With these data, we assess whether the results hold on a more granular level within the country that hosts the largest concentration of R&D subsidiaries in our dataset. To alleviate the concern that U.S. data disproportionately influences the findings, we also conduct analyses excluding U.S. R&D subsidiaries (see Appendix Table D.2).

Similar to our main specifications, we define a binary variable *Post-Broadband Introduction* that takes the value of one for the years following the entry of at least one broadband provider in the respective zip codes where the R&D subsidiary and its managing entity are located and zero otherwise. We adapt the PSM

[11] Data was collected from https://www.fcc.gov/form-477-data-zip-codes-number-high-speed-service-providers.

matching so that the managing entity must be in the U.S. for the U.S. R&D subsidiaries.[12] Appendix Table D.3 contains the balancing tests for the U.S. matched sample.

The results of the zip code-level analysis, presented in Table 7, corroborate those obtained at the country level. The DD model in Column 1 indicates that broadband introduction is associated with an average increase of 40.8% in the number of patents produced by R&D subsidiaries ($p<.05$). Columns 2 and 3 show the results of the DDD model. The fully saturated specification in Column 3 indicates that R&D subsidiaries managed by HQ experience, on average, a 77.2% smaller post-broadband increase in the number of patents invented than those managed by MS ($p<0.05$).

------Insert Table 7 About Here------

3.4. Conditions Influencing the Estimated Effect of Broadband on R&D Subsidiary Innovation

The next step in our investigation is to examine the conditions influencing the effect of broadband on R&D subsidiary innovation. We first test the assumption that broadband operates primarily through a communication channel between managing entities and R&D subsidiaries. This step is essential for our research goal because broadband may also directly benefit the R&D subsidiary. For instance, broadband may enable the R&D subsidiary to adopt faster testing techniques and laboratory equipment, improve remote work efficiency, and increase its capacity to process data from local or global sources (Akerman et al. 2015, Wu et al. 2020), all of which can boost subsidiary innovation without the managing entity's involvement.

To investigate whether the direct effect of broadband sufficiently explains the results, we create a binary indicator for *R&D Subsidiary Post-Broadband Introduction,* which is equal to one in the years after broadband penetration reaches the threshold rate in the R&D subsidiary's host-country. We then estimate the DDD specification in Equation 3 and exclude observations where the managing entity has broadband access. We do not find significant effects in Table 8, Columns 1 and 2. This suggests that the direct effects of broadband on the R&D subsidiary do not fully explain the results. We only find that the R&D subsidiaries experience significant increases in their innovation output when *both the managing entity and the R&D subsidiary have broadband access* (Table 6). Further evidence of the communication channel comes from the mechanism test in Section 3.5.1. These results are consistent with broadband as a communication channel between the managing entity and the R&D subsidiary and align with the dyadic nature of the benefits of communication technology discussed in extant work (e.g., Forman and van Zeebroeck 2019).

------Insert Table 8 About Here------

Second, we focus on the argument that the introduction of communication technology can be a shock

[12] Using the baseline DDD PSM matched sample results in a disproportionate number of HQ-managed R&D subsidiaries compared with MS-managed, however, it yields consistent results with Table 7.

to remote communication (Bertschek et al. 2013, Bloom et al. 2014). If this holds in our setting, we should observe the impact of broadband on innovation to increase with greater geographical distance between the R&D subsidiary and the managing entity (Bahar et al. 2023, Glaeser et al. 2022, Gumpert et al. 2022). To assess this, we gather data from the GeoDist database to measure the geographical distance between the countries of the R&D subsidiaries and their managing entities.[13] We then split our sample into two groups based on whether the distance between the managing entity and the R&D subsidiary is above or below the median. Table 9 shows that after broadband introduction, MS-managed subsidiaries located farther from their managing entities experienced a 29.8% post-broadband increase in patents ($p<0.01$), compared to a 23.9% increase for closer subsidiaries ($p>0.01$). While this pattern aligns with research suggesting that communication frictions increase with distance (Gumpert et al. 2022), the difference between the coefficients is not significant.

Taking these results together, we cannot conclude that inter-unit distance is a condition influencing the estimated effect of broadband on subsidiary innovation. However, both the R&D subsidiary and the managing entity having broadband access appear to be necessary conditions for the increase in innovation to be observed. Additionally, we will discuss a series of robustness checks in Section 4 to further assess whether the observed changes are attributable to broadband introduction. These checks include placebo tests, varying thresholds for broadband penetration, and alternative measures of innovation.

------Insert Table 9 About Here------

3.5. Exploring Mechanisms for the Larger Innovation Increase Among MS-Managed Subsidiaries

We now explore the potential mechanisms explaining why broadband is associated with greater increases in innovation among subsidiaries managed by MS than those managed by HQ. For this evaluation, we draw on the innovation management literature that consistently points to three channels through which managing entities influence R&D subsidiary innovation: sharing knowledge, funding R&D projects, and monitoring (Baaij and Slangen 2013, Berry 2015, Håkanson and Zander 1988, Manso 2011, Nobel and Birkinshaw 1998). We sequentially explore these channels below.

3.5.1. Knowledge Flows from the Managing Entity. Access to knowledge is essential for the innovation process, making its provision a vital role of the entity overseeing the R&D subsidiary (Feldman and Kogler 2010, Gupta and Govindarajan 2000, Teece 2010). Managing entities function as MNE integrators by

[13] This measure is calculated using the great circle formula, which determines the shortest distance between two points on Earth based on their latitudes and longitudes. The calculation focuses on the coordinates of the largest cities or urban centers by population and adjusts for internal country distances relative to geographic area. For additional information on this measure, see Mayer and Zignago (2011).

accumulating knowledge and disseminating it to R&D subsidiaries (Berry 2015, Lunnan and Zhao 2014). They often possess tacit knowledge that can assist subsidiaries in innovating (Teodorescu et al. 2022). However, the managing entity must engage in rich interactions to understand the contextual relevance of information and convey its meaning and value so that the R&D subsidiary can effectively combine it into a new invention (Singh 2008). Geographical separation creates communication frictions that complicate this, particularly for exchanging tacit knowledge, which often requires observation and demonstration (Polanyi 1966, Sorenson et al. 2006, Szulanski 1996, Teece 1977).

Broadband can reduce these frictions by enabling the transmission of large, complex data and remote visualization, facilitating tasks like plan presentations and prototype demonstrations without the need for in-person interactions (Bloom et al. 2014, Forman and van Zeebroeck 2019). This advanced communication medium enhances the managing entity's ability to more accurately identify and convey the specialized expertise required by the R&D subsidiary. It also reduces the friction for the R&D subsidiary to effectively receive and integrate the knowledge with its own.

If this channel explains our results, we should observe a larger post-broadband increase in knowledge flows from MS to their R&D subsidiaries than from HQ to their R&D subsidiaries. To explore this, we use the staggered DDD specification from Equation 3 and replace the dependent variable with *Knowledge Flows from the Managing Entity*. We measure knowledge flows using the natural log plus one of the annual number of backward citations (excluding examiner citations) to the managing entity's prior art not previously cited by the R&D subsidiary in the past five years, a common proxy for knowledge transfer and communication between parties (Bahar et al. 2023, Singh 2005, Sorenson et al. 2006).

Table 10 Column 3 shows that HQ-managed subsidiaries are associated with a 17.4% smaller post-broadband increase in knowledge flows relative to MS-managed subsidiaries ($p<0.05$). This common proxy for communication suggests that MS are comparatively more effective in leveraging broadband to share knowledge relevant to R&D subsidiary innovation, providing an explanation for the main findings.

A potential hypothesis is that broadband enables MS to better leverage their contextual intelligence and alignment with R&D subsidiaries to share knowledge that complements the R&D subsidiary's innovation process than HQ (Birkinshaw et al. 2006, Teodorescu et al. 2022). Alternatively, MS may foster routines that are more adaptive and responsive to new knowledge than HQ (Agrawal et al. 2014). Another possibility is that MS have global innovator or integrated player mandates that are associated with greater overall knowledge sharing compared to other roles (Gupta and Govindarajan 1991). Therefore, MS may be more likely to exploit broadband for this purpose than HQ. In contrast, the limited increase in knowledge flows from HQ to their subsidiaries suggests inefficiencies or restrictions that prevent HQ from fully capitalizing on reduced communication frictions. This could be due to more centralized and standardized processes, which are less flexible in addressing the specific needs of individual subsidiaries (Ambos and Schlegelmilch

2007, Nobel and Birkinshaw 1998). It is also possible that HQ may use broadband to prioritize corporate demands over sharing innovation-critical knowledge with their subsidiaries.

3.5.2. R&D Funding. The second channel we explore is the funding of R&D. Effective management requires allocating resources efficiently and aligning investments with firm strategy and the evolving market (Dellestrand and Kappen 2012, Hutchison-Krupat and Kavadias 2015, Seru 2014). This task is complicated by geographical distance, which creates friction for R&D subsidiaries to propose new project ideas to managing entities. It also increases information asymmetries, making it difficult for managing entities to understand which projects will likely result in successful inventions (Seru 2014).

Broadband can reduce these frictions by enabling more frequent interaction with managers for project pitching and for obtaining a better understanding of the R&D projects. It also enables greater visibility into subsidiary operations with tools like real-time financial tracking and forecasting software, helping managing entities assess project feasibility and allocate resources more effectively (D'Andrea and Limodio 2024, Forman and Van Zeebroeck 2012), which may ultimately boost innovation output from subsidiaries.

If R&D funding drives the results, we should observe significantly larger increases in funding among R&D subsidiaries managed by MS than those managed by HQ. To explore this, we run the baseline DDD specification of Equation 3 using the natural log of R&D expenditures as a dependent variable. The results in Columns 4 to 6 of Table 10 show no significant difference in the change in R&D expenditure between HQ-managed and MS-managed R&D subsidiaries. This suggests that increases in funding do not explain the greater post-broadband increase in innovation observed in MS-managed R&D subsidiaries.

3.5.3. Monitoring. Effective monitoring by managing entities is crucial to increase the likelihood of successful and valuable innovation (Azoulay et al. 2011, Manso 2011). This, however, requires communication (De Meyer and Mizushima 1989, Nobel and Birkinshaw 1998). It entails frequent interactions with R&D subsidiaries to help managing entities develop contextual knowledge, evaluate performance accurately, and provide timely feedback (Baaij and Slangen 2013, Manso 2011). Communication helps build rapport, enabling managing entities to obtain and interpret knowledge and information more effectively (Kogut and Zander 1992). In turn, high-quality monitoring reduces shirking and improves project execution and implementation (Nobel and Birkinshaw 1998).

Broadband can improve monitoring by lowering the cost of scheduled interactions and making frequent, rich communication between the managing entity and the R&D subsidiary comparatively feasible (Liberti and Petersen 2019). This enables managing entities to implement better control mechanisms that mitigate agency problems and foster more effective innovation processes, leading to increased innovation productivity (Glaeser et al. 2022, Manso 2011, Sorenson et al. 2006).

To explore whether this channel explains the results, we follow extant work and estimate R&D productivity, a traditional proxy for monitoring effectiveness, by including the log of R&D expenditure in the DDD specification (Aghion et al. 2013, e.g., Ahuja and Katila 2001). Prior research also suggests that by reducing communication costs, technologies such as broadband should improve the ability of managing entities to monitor a larger number of units, referred to in the literature as 'span of control' (Bloom et al. 2014, Garicano 2000, Rajan and Wulf 2006). If the managing entities are using broadband to improve the quality of their monitoring, we would expect that the effects of the reduction in communication costs on innovation productivity will be largest when the managing entity has a high span of control. To investigate this, we split the sample based on the median value of managing entity span of control. As shown in Table 10, MS-managed R&D subsidiaries experienced a 22.1% post-broadband increase in innovation productivity ($p<.001$), while HQ-managed subsidiaries saw a 29.0% smaller change ($p<.001$). Moreover, the introduction of broadband is associated with a larger increase in subsidiary innovation productivity for MS with a larger span of control. These results are consistent with MS leveraging broadband better to improve the quality of their monitoring of R&D subsidiaries than HQ.

One potential explanation for the results is that HQ may leverage broadband to exert control in a way that reduces R&D subsidiary motivation to innovate (Aghion and Tirole 1997). Scholars warn of the hazards of negative monitoring—exerting too much control that it reduces tolerance for failure, intrinsic motivation, and stifles creativity (Allen et al. 2015, Amabile 1988, Holmstrom 1989). Because managers at HQ are more proximate to shareholders and regularly report to the board of directors, they might face stronger pressure than MS to yield MNE fiscal performance (Balsmeier et al. 2017), leading to negative monitoring. If this were the case, based on prior research that has shown that managing entities are more likely to exert control when they have a smaller number of subsidiaries they manage, i.e. a smaller span of control (Aghion et al. 2014), we would expect that the negative effects will be largest when the managing entity controls fewer subsidiaries. Counter to this explanation, Table 10 Column 9 indicates that when the managing entity has above the median span of control, HQ-managed R&D subsidiaries performed relatively worse. A potential hypothesis is that the broader responsibilities at HQ might detract from its ability to use communication technologies effectively for monitoring purposes.

------Insert Table 10 About Here------

4. Specification Tests, Alternative Explanations, and Robustness

4.1. Alternative Dependent Variables: Innovation Quality and Market Value

While the results indicate that the post-broadband innovation output of MS-managed R&D subsidiaries increases more than that of HQ-managed subsidiaries, MS-managed subsidiaries may merely boost the number of patents produced without enhancing the quality or market value of their innovations. We use

innovation quality and market value as alternative dependent variables in the baseline DD and DDD specifications to explore this. The results presented in Table 11 are consistent with those for innovation output. Broadband introduction is associated with increases of 50.6% ($p<.01$) in innovation quality (Column 2) and 31.8% ($p<0.05$) in innovation market value (Column 6) for MS-managed R&D subsidiaries. HQ-managed subsidiaries exhibit, on average, smaller post-broadband changes of 45.8% ($p<.05$) in innovation quality and 47.8% ($p<.05$) in innovation market value compared to MS-managed subsidiaries.

------Insert Table 11 About Here------

4.2. DDD Specification Tests

4.2.1. Verifying Parallel Trends and Placebo Tests. We begin our specifications tests by examining the assumption of parallel trends for DDD analyses. That is, the assumption that in the absence of the treatment (broadband introduction), the difference between the treatment and control group would remain constant over time. Unlike standard DD models, the DDD estimator does not require two parallel trends for causal interpretation. Instead, the bias from two biased DD estimators cancels out (i.e., it is differenced out) if it is consistent across both estimators (Olden and Møen 2022). Therefore, the parallel trend assumption in our case applies only to the interaction term that compares changes in HQ- to MS-managed subsidiaries.

We visually assess the parallel trends assumption by splitting the HQ-Managed×Post-Broadband Introduction interaction term into four-year periods relative to the broadband introduction and graph the estimated coefficients. In Figure 3, the solid line represents the estimated coefficients, and the dotted line shows the 95% confidence intervals. Because our sample excludes observations with changes in management structure, the results can be interpreted as the relative four-year average change in innovation output for R&D subsidiaries under continued HQ management compared to MS management. The analysis shows no significant pre-trends, confirming adherence to the DDD parallel trend assumption, with a notable shift after the introduction of broadband.

For further evidence of the robustness of the analysis, we run placebo tests with one-, two-, and three-year leads on the post-broadband variable and its interaction with HQ-managed. The placebo analyses for our main dependent variable and the alternative dependent variables of innovation quality and market value provide evidence that the results are not likely driven by spurious time effects (Appendix D, Table D.4).

----Insert Figure 3 here----

4.2.2. Staggered Difference-in-Differences Heterogeneous and Dynamic Effects Tests. Recent research on staggered difference-in-differences highlights potential biases that can emerge if treatment timings and effects are heterogeneous (Baker et al. 2022, Callaway and Sant'Anna 2021). This is because two-way fixed effects compute the weighted average from: 1) comparing treated with untreated units, and 2) comparing treated with pre-treated units. The second comparison can cause the weights to become

negative, even if the treated effect is positive (De Chaisemartin and d'Haultfoeuille 2020, Goodman-Bacon 2021). This potential concern may arise in our long sample because early treatments may differ significantly from later ones, with heterogeneity in treatment effects potentially driven by technological advancements. Additionally, the treatment effect may evolve over time. This could occur if post-introduction complementary technologies, infrastructure improvements, and learning curves cause the impact of broadband to change as exposure to it increases.

Testing for these biases in our case is complex due to the triple difference-in-differences design involving an unbalanced panel with a time-constant interaction term, which most current methods have yet to fully address. Our strategy involves a combination of two procedures. To understand how treatment timings might be associated with the heterogeneous effects of broadband, we implement the Wooldridge (2021) procedure, which involves creating binary indicators for each group of R&D subsidiaries receiving treatment in each period or "cohort." This allows flexible estimation of changes in R&D subsidiary innovation by time cohort, while effectively addressing biases in DDD models with unbalanced panel data. Due to limited observations and following Wooldridge's (2021) recommendation, we combine the first and last three years of our sample period into two respective cohorts, treating all other years as individual cohorts. Running each year as a separate cohort yields consistent coefficient signs but larger standard errors. In Appendix Table D.5, we find that each cohort shows results similar to our main analysis regarding the estimated effects of broadband and HQ management on R&D subsidiary innovation. These effects are not trending and overall suggest that the analysis does not suffer from heterogeneous treatment effects.

Next, we use the estimator from de Chaisemartin et al. (2024), which is robust to heterogeneous and dynamic treatment effects. This approach generates dynamic effect estimates by comparing outcome changes between units that switched to treatment ℓ years before and those yet to be treated. It also computes the average heterogeneity-robust effects as a weighted sum of instantaneous and dynamic effects by HQ-managed and MS-managed R&D subsidiaries. As shown in Appendix D Table D.6, consistent with the main results in Columns 2-5 of Table 6, the average total heterogeneity-robust effect for MS-managed subsidiaries is positive and significant (coefficient = 0.244, $p<0.05$). In contrast, for HQ-managed subsidiaries, it is negative and non-significant ($p<0.10$). Examining effects over each ℓ year since treatment, we find that dynamic effects are non-significant ($p = 0.252$ for HQ-managed and $p = 0.166$ for MS-managed). Additionally, placebo tests indicate that the three years before treatment do not significantly differ from zero ($p = 0.27$ for HQ-managed and $p = 0.98$ for MS-managed), aligning with the earlier placebo tests in Section 4.2.1.

4.3. Different Thresholds for Broadband Introduction

We test alternative thresholds for broadband penetration at the 3.0%, 7.0%, and 9.0% penetration rates in

both the R&D subsidiary's and managing entity's countries. At the 3.0% threshold, we do not find evidence that broadband is associated with changes in R&D subsidiary innovation output. However, after surpassing the 5.0% threshold, broadband consistently significantly is associated with increases in MS-managed R&D subsidiary innovation, with similar results to Table 6 at higher thresholds (see Appendix D Table D.7).

4.4. Within-MNE and Within-Subsidiary Differences

We assume broadband availability is linked to its adoption due to its low implementation costs and potential for substantial productivity gains. However, MNEs may have unobserved heterogeneity that affects their likelihood of adopting broadband once introduced. To evaluate the risk of this heterogeneity biasing the results, we conduct within-MNE tests incorporating MNE×year fixed effects and find consistent results, as shown in Appendix D Table D.8.

Similarly, there is a risk that unobserved differences between HQ- and MS-managed R&D subsidiaries escaped our matching procedures to reduce the systematic differences in R&D subsidiary productivity and managing entity type. For example, MS-managed R&D subsidiaries may also receive resources and attention from HQ, artificially inflating the coefficients of MS management. To further address these endogeneity concerns, we exploit instances where R&D subsidiaries are jointly managed by both HQ and MS and trace communication patterns of the knowledge flows from each managing entity directly affecting the R&D subsidiary's innovation outputs. This within-subsidiary analysis helps control for the effects of dual management and offers further robustness against unobserved subsidiary-specific traits. Appendix D Table D.9 shows that post-broadband R&D subsidiaries managed by both HQ and MS have significantly smaller changes in knowledge flows from HQ compared to MS. This supports the idea that broadband influences the efficacy of knowledge transfer differently across managing entity types.

4.5. Additional Robustness

We conduct several additional robustness tests. First, the matching algorithm employs many variables, including matching on country. Therefore, we test alternative matched samples with fewer variables, which results in more matches, and find consistent results. Second, we also assess the sensitivity of the analyses by excluding key countries—China, France, Germany, India, Taiwan, the United Kingdom, and the United States—one by one, as they have more R&D subsidiaries in the sample. Removing each country did not affect the results (Appendix D, Table D.2). Third, since regional headquarters may perform functions similar to corporate headquarters, we examine the results by reclassifying the 34 observations involving regional headquarters as corporate HQs. We find that it does not alter the main findings. Finally, we employ Poisson pseudo-maximum likelihood regressions with subsidiary fixed effects on the non-logged innovation variables with consistent results.

5. Discussion

Firms often assign control of R&D subsidiaries to MS rather than centralizing it under HQ (Nell et al. 2017, Verbeke and Yuan 2018). Despite the ubiquity of MS in MNEs across industries and countries, systematic empirical research has predominantly focused on HQ's central role in firm innovation (Dellestrand and Kappen 2012). Consequently, the conditions under which R&D subsidiaries generate more innovation under HQ or MS management, especially given the communication advancements of the 21st century, have remained an open empirical question.

In addressing this gap, we contribute to three main research streams. To the MNE innovation management literature (Berry 2015, Glaeser et al. 2022, Nobel and Birkinshaw 1998), this study provides the first large-scale empirical investigation comparing HQ- and MS-managed R&D subsidiary innovation output. The findings speak to the active debate questioning the headquarter-centric view and the value of headquarters (Ciabuschi et al. 2017, Nell and Ambos 2013) amidst growing evidence on the prevalence of MS (Verbeke and Yuan 2018). The findings suggest that advances in communication technologies are shifting the effectiveness of MS in managing R&D subsidiaries compared to HQ, yielding significant enhancements in knowledge flows and monitoring and leading to increased R&D subsidiary productivity.

Our findings challenge a longstanding assumption and highlight promising opportunities to better align theory with the practical realities of managing geographically dispersed R&D. If MS's advantage over HQ lies in mitigating communication frictions due to organizational and physical proximity to R&D subsidiaries (Gumpert et al. 2022), then the introduction of broadband should have diminished this benefit. However, the analysis robustly indicates that MS-managed R&D subsidiaries exhibit substantially greater post-broadband increases in innovation output, quality, and market value than those managed by HQ.

Overall, the results suggest that the value of MS for MNEs is richer and more complex than reducing geographic friction with dispersed subsidiaries—the most common argument in the literature. Insights from the analysis point to a hypothesis that improvements in communication technologies may empower MS to capitalize more effectively on their contextual alignment with the operational environment of R&D subsidiaries. Compared to HQ, MS's regional expertise and understanding of subsidiaries' operational landscapes may lead MS to leverage communication enhancements for: (i) more targeted data collection and knowledge absorption and (ii) more effective tailoring of data and knowledge that meets R&D subsidiaries' processing capacities and needs.

Another potential hypothesis is that MS may possess mandates that equip it with more relevant knowledge to share with its R&D subsidiaries than HQ. For example, MS may have manufacturing mandates that offer opportunities for cross-value-chain learning with R&D, but effective communication is necessary to fully realize these benefits (Andersson et al. 2015, Berry and Kaul 2015). A potential fruitful

line of inquiry would be to explore how managing entity mandates influences the effectiveness of HQ versus MS in managing R&D subsidiaries in this technologically shifting landscape.

Importantly, this study does not suggest that HQ delivers subpar management. Plausibly, MNEs more frequently optimize the productivity of R&D subsidiaries under HQ control, rendering the marginal benefits of enhanced communication comparatively low. Indeed, we found that post-broadband changes in the innovation outputs of HQ-managed R&D subsidiaries were statistically insignificant.

To research on the (de)centralization of R&D management, this study offers a more functional characterization of R&D structures within MNEs. The literature simplifies this decision to HQ control or autonomous front-line subsidiaries. This disconnect between theory and practice partly arises from the challenges in accurately documenting innovation management structures within large firms. To address this challenge, we leveraged confidential transfer pricing reports to build a longitudinal panel of intra-firm activities for a diverse set of MNEs. Due to their comprehensive information and critical legal importance, these reports clearly identify the R&D subsidiaries and their managing entities. The analyses illuminate the importance of MS as an alternative to centralization of management in headquarters.

This study also contributes to the literature on the impact of communication technologies on firm performance by helping to explain the heterogeneous effects of these technologies, a longstanding puzzle in the literature (Bloom et al. 2012, Schreyer 2000, Stiroh 2002). We provide evidence that broadband is associated with an average positive increase in innovation output. At the same time, the unequal distribution of this relationship across R&D subsidiaries indicates that the internal organization of firms is crucial to understanding how and when firm performance benefits from technological advancements.

HQs, particularly those with extensive spans of control, seem less adept at translating the reduction in communication costs into effective oversight of subsidiaries. This argument resonates with past literature suggesting that HQ often deals with competing bureaucratic and corporate-level processes (Kostova et al. 2016). These competing demands may be less frequent for managers in MS (Ciabuschi et al. 2012, Dessein and Santos 2021, Mahnke et al. 2012). HQ may use broadband to satisfy other corporate demands.

The results suggest that a communication channel with the managing entity is essential for the estimated effect of broadband on innovation to be observable. We find that the direct effects of broadband on R&D subsidiaries alone do not fully explain the increase in subsidiary innovation, aligning with the well-discussed argument of the dyadic benefits of communication technology (e.g., Forman and van Zeebroeck 2019). Specifically, the estimated effect on R&D subsidiary innovation is not statistically different from zero when the managing entity does not have broadband access. Similarly, setting the staggered treatments years before the technology rollout does not replicate the effect.

Our study has several limitations. First, while using the transfer pricing reports strengthens the internal validity of the analysis, the findings might not be generalizable to all MNEs, especially the very largest

MNEs. Although we confirm the statistical similarity across a set of variables of the MNEs in our sample with several other datasets at the international level, future research can study different samples to understand how firm heterogeneity may affect the results.

Second, the analysis holds constant the structure of innovation management, but firms might undergo organizational improvements in response to new technologies (Bloom et al. 2012, Bresnahan et al. 2002), which could affect the observed outcomes. For instance, broadband may have helped MS more than HQ to improve talent recruitment, training, automation, or simply better practices in the innovation process. These factors may precede knowledge transfer and monitoring, the two mechanisms associated with the post-broadband differences between MS-managed and HQ-managed R&D subsidiaries. More granular data tracking longitudinal changes in the managing and managed entities has the potential to delve deeper into the 'why' broadband can result in larger innovation improvements for MS-managed R&D subsidiaries.

Third, consistent with studies examining flight pattern changes, economic productivity, and innovation outcomes (Bahar et al. 2023, Bernstein et al. 2016, Catalini et al. 2020), our empirical strategy does not directly observe the interactions between managing entities and R&D subsidiaries. It is plausible that the proxies in the analysis provide a rather constrained perspective of the argued mechanisms. For instance, patent citations likely explain a rather small portion of the wealth of innovation-relevant knowledge flows between the managing entities and subsidiaries. Microlevel data covering the interactions between supervisors and inventors could extend the findings in this study by helping identify the type(s) of communication that matters the most for the productivity of R&D subsidiaries.

Fourth, our approach may not fully account for the direct effects of broadband on innovation outputs that occur independently of the managing entity and through mechanisms not fully explored in this study. For instance, broadband can enhance data processing and improve real-time decision-making (Wu et al. 2020), which could contribute to innovation outcomes. Future research could benefit by disentangling these direct effects from those associated with managing entities, using more granular data across different organizational levels. This would provide a more comprehensive understanding of how this type of technology contributes to innovation beyond the scope of inter-entity coordination.

Finally, our primary focus on cross-country variation in broadband penetration is driven by our goal of understanding how the managing entity type, a central choice for R&D management, affects innovation, particularly in the context of increasingly geographically dispersed innovation activities. However, this approach may overlook important within-country variations in broadband availability and quality. For instance, faster-growing countries or those with a higher concentration of skilled workers may adopt broadband earlier, potentially introducing biases in the analysis. Although we explicitly address these concerns in our specifications, within-country differences remain an important area for future research.

Exploring these variations could provide deeper insights into how access to communication technology shapes innovation outcomes at a more granular level.

This study has implications for managers of MNEs. The findings can guide firms in understanding the tradeoffs between HQ and MS R&D management. While, on average, HQ may have more fiscal and knowledge resources, when both the managing entity and the R&D subsidiary have access to technologies that facilitate knowledge flows and remote monitoring, MS may enable MNEs to achieve more substantial increases in innovation outcomes.

A central insight from our investigation is that the fast and uncertain operational landscapes that MNEs face worldwide heighten the importance of organizational design in their ability to perceive, seize, and integrate opportunities arising from environmental changes like broadband introduction. This study highlights how MS can equip the MNE with agility. The results suggest that MS, particularly those with higher spans of control and greater geographical distances, may leverage communication technology advancements to identify and integrate opportunities across the MNE to the R&D subsidiaries they manage, driving increased innovation output. This study highlights how firms' choices regarding HQ- and MS-management of R&D subsidiaries can help explain the competitive advantages that arise during waves of technological disruption.

In conclusion, this study reexamines the traditional HQ-centric paradigm of innovation management and systematically evaluates the comparative benefits of MS, especially amid technological advancements like broadband. We provide robust empirical evidence on the conditions and mechanisms under which MS-managed R&D subsidiaries are associated with greater increases in innovation than HQ. In this way, our study fills a significant gap in the management of MNE innovation. It offers actionable insights for MNEs on overseeing geographically dispersed. The findings pave the way for future research and practical applications, highlighting the transformative potential of embracing MS innovation management in the digital age.

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Tables and Figures
Table 1

Distribution of R&D Subsidiaries

	Proportion of Total				Proportion of Total		
	Headquarters-Managed	Subsidiary-Managed	Broadband Introduction Year		Headquarters-Managed	Subsidiary-Managed	Broadband Introduction Year
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 managed 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 2

R&D Subsidiaries by Managing Entity Type

Variable	Number of Observations (1)	All (2)	Headquarters-Managed (3)	Subsidiary-Managed (4)	Headquarters-Managed Only (5)	Headquarters and Subsidiary-Managed (6)	Subsidiary-Managed Only (7)
Broadband Introduction Year	4,009	2005	2005	2005	2005	2005	2005
Panel A: Pre-Broadband							
Innovation Output	1,570	0.282	0.233	0.270	0.320	0.168	0.341
Innovation Quality	1,413	0.298	0.305	0.253	0.452	0.203	0.289
Innovation Market Value	1,482	0.513	0.381	0.518	0.496	0.299	0.681
Panel B: Post-Broadband							
Innovation Output	2,439	0.483	0.303	0.568	0.274	0.335	0.702
Innovation Quality	1,856	0.525	0.382	0.584	0.393	0.369	0.720
Innovation Market Value	2,112	0.760	0.416	0.937	0.361	0.477	1.239
Panel C: Full Sample							
Innovation Output	4,009	0.404	0.276	0.446	0.290	0.262	0.561
Innovation Quality	3,269	0.427	0.350	0.432	0.414	0.289	0.528
Innovation Market Value	3,594	0.659	0.402	0.754	0.408	0.396	1.002

Notes. This table contains the respective sample mean values of Broadband Introduction Year, Innovation Output, Quality, and Market Value. Broadband Introduction Year represents the mean year that broadband is introduced both in the R&D subsidiary and managing entity locations. 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 managing entity country locations. Post-broadband represents the sample of R&D subsidiaries after broadband technology is introduced in both the R&D subsidiary and managing entity country locations. Innovation Output 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 Output, Quality, and Market Value reflect the natural logarithm values of innovation outcomes plus one. The full sample is used for Innovation Output. 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 3a
Propensity Score Balancing Test for Pre-Broadband Baseline OLS Analysis

Variable	Unmatched (U) Matched (M) Samples (1)	Mean HQ-Managed (2)	Mean MS-Managed (3)	% Bias (4)	% Reduced Bias (5)	t-test t (6)	t-test p>t (7)
Subsidiary and Managing Entity Geographical Distance	U	6395.6	4772.5	35.0		4.12	0.000
	M	4620.9	5169.2	-11.8	66.2	-1.05	0.295
Subsidiary and Managing Entity Cultural Distance	U	30.895	29.102	5.8		0.68	0.499
	M	22.755	27.721	-15.9	-176.9	-1.40	0.163
Subsidiary and Managing Entity Same Language	U	0.514	0.376	28.0		3.28	0.001
	M	0.531	0.429	20.7	26.2	1.75	0.080
MNE Size	U	14.160	15.985	-93.0		-11.07	0.000
	M	14.858	15.158	-15.3	83.6	-1.28	0.201
MNE Diversification	U	0.545	0.617	-13.6		-1.60	0.111
	M	0.538	0.550	-2.3	83.0	-0.21	0.836
MNE Stock Compensation Expense	U	7.663	6.871	16.2		1.93	0.054
	M	7.976	7.411	11.5	28.6	1.07	0.284
Host-Country Revealed Technological Advantage	U	0.836	0.843	-1.4		-0.16	0.872
	M	0.858	0.862	-0.7	51.3	-0.06	0.956
Host-Country Industry Market Concentration	U	0.473	0.481	-10.7		-1.28	0.203
	M	0.468	0.481	-17.2	-59.8	-1.63	0.105

Notes. The balancing test shows the mean pre-broadband values of the variables.

Table 3b
Propensity Score Balancing Test for Difference-in-Differences and Triple Difference-in-Differences

Variable	Unmatched (U) Matched (M) Samples (1)	Mean HQ-Managed (2)	Mean MS-Managed (3)	% Bias (4)	% Reduced Bias (5)	t-test t (6)	t-test p>t (7)
Subsidiary Innovation Output	U	0.128	0.116	3.5		0.40	0.693
	M	0.089	0.131	-11.9	-240.6	-1.05	0.296
Subsidiary Innovation Quality	U	0.145	0.164	-3.5		-0.40	0.689
	M	0.072	0.167	-18.2	-422.3	-1.77	0.078
Subsidiary Innovation Market Value	U	0.149	0.102	8.6		0.98	0.326
	M	0.098	0.122	-4.2	51.5	-0.37	0.714
Subsidiary Ln R&D	U	1.670	2.101	-18.6		-2.19	0.029
	M	2.129	1.826	13.1	29.6	1.15	0.251
Subsidiary Role	U	1.586	1.546	5.9		0.68	0.494
	M	1.668	1.596	10.5	-76.5	0.83	0.407
Subsidiary Knowledge Flows from Managing Entity	U	0.026	0.039	-5.7		-0.66	0.509
	M	0.027	0.043	-7.4	-29.4	-0.59	0.558
Subsidiary and Managing Entity Geographical Distance	U	6300.5	4704.0	34.5		3.97	0.000
	M	4817.0	5454.5	-13.8	60.1	-1.13	0.258
Subsidiary and Managing Entity Cultural Distance	U	30.712	28.394	7.5		0.86	0.391
	M	24.190	28.337	-13.4	-78.9	-1.09	0.275
Subsidiary and Managing Entity Same Language	U	0.515	0.380	27.3		3.12	0.002
	M	0.504	0.442	12.6	53.9	1.00	0.320
Managing Entity Innovation Output	U	0.486	0.651	-12.6		-1.46	0.145
	M	0.562	0.775	-16.2	-28.6	-1.18	0.240
Managing Entity Ln R&D	U	2.807	2.171	22.4		2.55	0.011
	M	2.934	2.598	11.8	47.1	0.91	0.365
MNE Size	U	14.123	15.971	-93.8		-10.89	0.000
	M	14.718	14.973	-12.9	86.2	-0.98	0.327
MNE Diversification	U	0.512	0.620	-20.4		-2.35	0.019
	M	0.469	0.468	0.2	99.2	0.02	0.988
MNE Stock Compensation Expense	U	7.449	6.794	13.3		1.55	0.121
	M	7.542	7.588	-0.9	93.0	-0.08	0.936
Host-Country Revealed Technological Advantage	U	0.836	0.854	-3.6		-0.42	0.674
	M	0.861	0.839	4.2	-16.9	0.33	0.739
Host-Country Industry Market Concentration	U	0.474	0.481	-8.9		-1.03	0.302
	M	0.471	0.475	-5.4	38.9	-0.45	0.655

Notes. The balancing test shows the mean pre-treatment values of the variables.

Table 4 Descriptive Statistics Full Dataset

Variable	Obs	Mean	Std. dev.	Min	Max
Subsidiary, MNE, and Host-Country Industry Variables					
Innovation Output	3,764	1.970	7.546	0.000	110.000
Innovation Quality	3,079	4.369	25.769	0.000	611.000
Innovation Market Value	3,366	43.88	291.50	0.000	7035.42
Post-Broadband Introduction	3,764	0.611	0.488	0.000	1.000
Headquarters-Managed	3,764	0.562	0.496	0.000	1.000
MNE Size (millions USD)	3,764	22300	70200		
MNE Diversification	3,764	0.641	0.559		
MNE Stock Compensation Expense (thousands USD)	3,764	124056	202686		
Host-Country-Industry Revealed Technological Advantage	3,764	0.877	0.511	0.000	3.636
Host-Country-Industry Market Concentration	3,764	0.483	0.070	0.000	0.520
Subsidiary R&D Expenses (thousands USD)	3,701	5858	294260		
Subsidiary Role	3,764	1.592	0.763	0.000	4.000
Dyadic Variables					
Knowledge Flows from Managing Entity	6,865	0.989	6.332	0.000	246.000
Subsidiary and Managing Entity Physical Distance	6,639	4837	4194	9.560	19147
Subsidiary and Managing Entity Cultural Distance	6,429	24.178	28.188	0.000	157.64
Subsidiary and Managing Entity Same Language	6,633	0.409	0.492	0.000	1.000
Matched Sample for R&D Subsidiaries with One Managing Entity Only					
Innovation Output	981	0.362	1.086	0.000	14.000
Innovation Quality	854	0.870	4.376	0.000	65.000
Innovation Market Value	885	2.060	11.320	0.000	198.132
Knowledge Flows from Managing Entity	981	0.105	0.998	0.000	24.000
Post-Broadband Introduction	981	0.640	0.480	0.000	1.000
Headquarters-Managed	981	0.487	0.500	0.000	1.000
MNE Size (millions USD)	981	20800	57700		
MNE Diversification	981	0.517	0.520		
MNE Stock Compensation Expense (thousands USD)	981	99647	177308		
Host-Country-Industry Revealed Technological Advantage	981	0.893	0.545	0.000	3.636
Host-Country-Industry Market Concentration	981	0.482	0.071	0.000	0.520
Subsidiary R&D Expenses (thousands USD)	981	210.698	1878		
Subsidiary Role	981	1.627	0.724	0.000	4.000
Subsidiary and Managing Entity Physical Distance	981	5095	4372	76.427	19147
Subsidiary and Managing Entity Cultural Distance	981	25.408	29.248	0.000	115.470
Subsidiary and Managing Entity Same Language	981	0.431	0.495	0.000	1.000

Notes. This table contains the descriptive statistics for the various samples based on the fully loaded model. 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). The number of observations increases for the dyadic variables as it represents the dyadic-level relationship between entities. The PSM matched sample uses a vector of mean pre-treatment variables that can affect innovation outcomes for the R&D subsidiaries that have only one managing entity only to isolate the effects of HQ vs MS-management. To comply with the confidentiality agreement, only aggregated statistics are presented for MNE variables and R&D expenses, and the minimum and maximum values are not reported.

Table 5 Random Effects OLS Results for Headquarters-Managed vs Subsidiary-Managed Innovation Pre-Broadband

	Full Sample		Matched Sample	
	Innovation Output	**Innovation Productivity**	**Innovation Output**	**Innovation Productivity**
	(1)	**(2)**	**(3)**	**(4)**
Headquarters-Managed	0.045	0.049	0.171	0.171
	(0.061)	(0.061)	(0.086)	(0.085)
	[0.459]	[0.422]	[0.046]	[0.044]
Subsidiary R&D	No	Yes	No	Yes
Country and MNE Controls	Yes	Yes	Yes	Yes
Subsidiary Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Number of Observations	1424	1424	457	457
Number of Clusters	561	561	190	190
R-Squared	0.239	0.244	0.272	0.274

Notes. This table presents the random effects OLS estimates of Headquarters-Managed and innovation output and productivity. Innovation Output represents the natural log of one plus the total number of patents invented by the R&D subsidiary in the given year. Innovation Productivity controls for R&D expenditures in estimating the number of patents produced. The full sample pre-broadband contains the observations prior to broadband introduction. The Matched Sample Pre-Broadband contains the pre-broadband PSM matched sample of R&D subsidiaries managed by headquarters to those managed by subsidiaries with one managing relationship only. All models are estimated with robust standard errors clustered at the subsidiary level. Standard errors are in parentheses and p-values are in brackets.

Table 6 The Estimated Effect of Broadband on the Relationship between R&D Subsidiary Innovation and the Type of Managing Entity

	Difference-in-Differences Analysis					Triple Difference-in-Differences Analysis			
	All R&D Subsidiaries	HQ-Managed R&D Subsidiaries		MS-Managed R&D Subsidiaries		Full Sample		Matched Sample	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Post-Broadband Introduction	0.087	0.007	0.012	0.170	0.191	0.180	0.203	0.189	0.221
	(0.027)	(0.035)	(0.037)	(0.040)	(0.042)	(0.039)	(0.042)	(0.060)	(0.064)
	[0.001]	[0.852]	[0.746]	[0.000]	[0.000]	[0.000]	[0.000]	[0.002]	[0.001]
Headquarters-Managed* Post-Broadband Introduction						-0.178	-0.201	-0.248	-0.290
						(0.049)	(0.054)	(0.086)	(0.088)
						[0.000]	[0.000]	[0.004]	[0.001]
Control Variables	No	No	Yes	No	Yes	No	Yes	No	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Headquarters-Managed-Year Fixed Effects	No	No	No	No	No	Yes	Yes	Yes	Yes
Number of Observations	4009	2199	2086	1938	1785	4009	3764	1013	981
Number of Clusters	946	510	496	480	454	946	914	258	258
R-squared	0.052	0.035	0.033	0.104	0.114	0.066	0.070	0.070	0.088

Notes. This table presents the difference-in-differences estimates of the introduction of broadband technology and innovation output for the full sample in Column 1, the sample of headquarters-managed R&D subsidiaries in Columns 2-3, and the sample of subsidiary-managed R&D subsidiaries in Columns 4-5. Columns 6-7 and 8-9 contain the triple difference estimates of the effect of broadband introduction on the innovation of R&D subsidiaries managed by headquarters vis-à-vis those managed by other subsidiaries for the full sample and then the PSM matched sample, respectively. The PSM matched sample uses a vector of mean pre-treatment variables that can affect innovation outcomes. Changes in sample size are due to missing control data. 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 managing-entity country. Headquarters-Managed*Post-broadband Introduction reflects the interaction term of the binary indicator for headquarters-managed R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-managed R&D subsidiary is absorbed by subsidiary fixed effects. Innovation Output represents the natural log of one plus the total number of patents invented by the R&D subsidiary in the given year. 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 7 The Estimated Effect of Broadband at the US Zip Code Level on R&D Subsidiary Innovation Output for US R&D Subsidiaries with US Managing Entities

	Matched Sample		
Dependent Variable = ln (Number of Patents +1)	**(1)**	**(2)**	**(3)**
US Zip Codes Post-Broadband Introduction	0.342	0.371	0.547
	(0.140)	(0.218)	(0.134)
	[0.018]	[0.095]	[0.000]
US Headquarters-Managed* US Zip Codes Post-Broadband Introduction		-0.854	-0.572
		(0.260)	(0.257)
		[0.002]	[0.031]
Country and MNE Controls	No	No	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Headquarters-Managed-Year Fixed Effects	No	Yes	Yes
Number of Observations	172	172	172
Number of Clusters	52	52	52
R-squared	0.129	0.210	0.334

Notes. This table presents the difference-in-differences estimates of the introduction of broadband technology and innovation output in Columns 1. The remaining columns contain the triple difference estimates of the effect of US zip code broadband introduction on the innovation of US R&D subsidiaries managed by US headquarters vis-à-vis those managed by other US subsidiaries. The PSM matched sample uses a vector of mean pre-treatment variables that can affect innovation outcomes. US Zip Code Post-Broadband Introduction is a binary indicator for whether there are suppliers of broadband in the zip code location for both the R&D subsidiary-zip code and the managing-entity zip code. Headquarters-Managed*Post-broadband Introduction reflects the interaction term of the binary indicator for headquarters-managed R&D subsidiary with the binary indicator for US zip code post-broadband introduction. The main effect for the binary indicator for headquarters-managed R&D subsidiary is absorbed by subsidiary fixed effects. Innovation Output represents the natural log of one plus the total number of patents invented by the R&D subsidiary in the given year. 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 8
Conditions Test: R&D Subsidiary has Broadband Access, Managing Entity Does Not Have Broadband Access

	Full Sample	Matched Sample
Dependent Variable= ln (Number of Patents +1)	**(1)**	**(2)**
R&D Subsidiary Post-Broadband Introduction	0.021	0.089
	(0.029)	(0.096)
	[0.477]	[0.355]
Headquarters-Managed*R&D Subsidiary Post-Broadband Introduction	0.004	0.114
	(0.038)	(0.163)
	[0.921]	[0.486]
Control Variables	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Headquarters-Managed-Year Fixed Effects	Yes	Yes
Number of Observations	1436	210
Number of Clusters	549	115
R-Squared	0.071	0.426

Notes. R&D Subsidiary Post-Broadband Introduction is a binary indicator for whether the broadband penetration rate has reached or surpassed five percent market penetration rate for the R&D subsidiary-country. The sample excludes observations where the managing entity has had broadband introduced in its location. The dependent variable is innovation output calculated as the natural log of one plus the total number of patent applications filed by the R&D subsidiary in the given year. Headquarters-Managed*Post-Broadband Introduction reflects the interaction term of the binary indicator for headquarters-managed R&D subsidiary with the binary indicator for R&D Subsidiary Post-Broadband Introduction. The main effect for the binary indicator for headquarters-managed 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 9
Conditions Test: Split Sample Analysis for the Estimated Effect of Broadband and Geographical Distance

Dependent Variable= ln (Number of Patents +1)	Geographical Distance Low **(1)**	Geographical Distance High **(2)**
Post-Broadband Introduction	0.214	0.261
	(0.086)	(0.104)
	[0.014]	[0.013]
Headquarters-Managed* Post-Broadband Introduction	-0.268	-0.341
	(0.115)	(0.146)
	[0.022]	[0.021]
Control Variables	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Headquarters-Managed-Year Fixed Effects	No	Yes
Number of Observations	513	468
Number of Clusters	137	121
R-Squared	0.116	0.087
Split Sample Comparison		
Post-Broadband Introduction F-Statistic		0.20
P-value		0.653
Headquarters-Managed* Post-Broadband Introduction F-statistic		0.25
P-value		0.616

Notes. The PSM matched sample is split in Columns 1-2 based on the median value of geographical distance between the R&D subsidiary and managing 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 managing-entity country. The dependent variable is innovation output calculated as the natural log of one plus the total number of patent applications filed by the R&D subsidiary in the given year. Headquarters-Managed*Post-Broadband Introduction reflects the interaction term of the binary indicator for headquarters-managed R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-managed 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 10

Exploring the Mechanisms Explaining the Post-Broadband Differences in HQ and MS-Managed R&D Subsidiary Innovation

	Mechanism 1:			Mechanism 2:			Mechanism 3:		
	Knowledge Flows from Managing Entity			R&D Funding			Innovation Productivity	Monitoring Span of Control	
								Low	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post-Broadband Introduction	0.008	0.091	0.101	0.336	0.315	0.294	0.221	0.116	0.285
	(0.037)	(0.047)	(0.051)	(0.125)	(0.201)	(0.222)	(0.064)	(0.087)	(0.096)
	[0.838]	[0.056]	[0.047]	[0.008]	[0.119]	[0.186]	[0.001]	[0.184]	[0.003]
Headquarters-Managed* Post-Broadband Introduction		-0.167	-0.174		0.059	0.064	-0.290	-0.164	-0.378
		(0.073)	(0.080)		(0.243)	(0.260)	(0.088)	(0.107)	(0.136)
		[0.023]	[0.030]		[0.807]	[0.806]	[0.001]	[0.126]	[0.006]
Subsidiary R&D	No	No	No	No	No	No	Yes	Yes	Yes
Control Variables	No	No	Yes	No	No	Yes	Yes	Yes	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Headquarters-Managed-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	1013	1013	981	571	571	563	981	490	491
Number of Clusters	258	258	258	196	196	196	258	135	123
R-squared	0.013	0.043	0.05	0.052	0.13	0.147	0.088	0.148	0.129
Split Sample Comparison									
Post-Broadband Introduction F-Statistic									3.80
p-value									[0.053]
Headquarters-Managed* Post-Broadband Introduction F-statistic									3.99
p-value									[0.048]

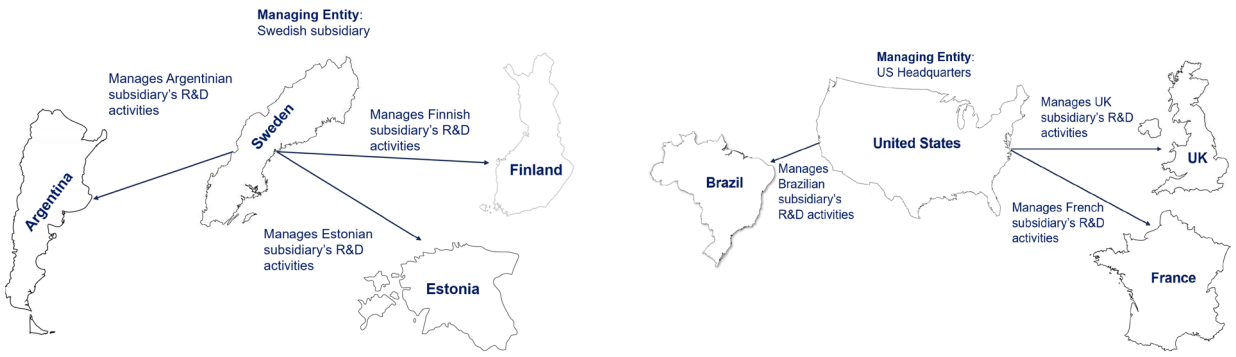
Notes. Estimated on the PSM matched sample. This table contains the DD and DDD estimates of the effect of broadband introduction on knowledge flows from managing entity (Columns 1-3), R&D funding (Columns 4-6), and innovation output (Columns 7-9). The regressions for Columns 7-9 include R&D expenditures to estimate innovation productivity. The sample is split based on the median value of Span of Control (Columns 8 and 9). The dependent variable Knowledge Flows from Managing Entity is the proportion of R&D subsidiary citations in a given year to prior art invented by the managing entity that the R&D subsidiary had not previously cited in the past five years. R&D Funding is the natural log of subsidiary R&D expenditures. The sample size is reduced in columns 4-6 due to missing observations because the dependent variable is predicting the R&D expenditures, rather than using lagged R&D expenditures used in other analyses. The dependent variable innovation output calculated as the natural log of one plus the total number of patent applications filed by the 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 managing entity country. The main effect for the binary indicator for headquarters-managed R&D is absorbed by dyadic fixed effects. All models are estimated using fixed effects OLS with robust standard errors clustered at the subsidiary level. Standard errors are in parentheses and p-values are in brackets.

Table 11 Alternative Measures of Innovation Output: Innovation Quality and Innovation Market Value

	Innovation Quality					Innovation Market Value				
	Full Sample			Matched Sample		Full Sample			Matched Sample	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
Post-Broadband Introduction	0.136	0.237	0.284	0.449	0.506	0.197	0.384	0.437	0.244	0.318
	(0.048)	(0.080)	(0.087)	(0.167)	(0.179)	(0.063)	(0.100)	(0.108)	(0.143)	(0.155)
	[0.005]	[0.003]	[0.001]	[0.008]	[0.005]	[0.002]	[0.000]	[0.000]	[0.089]	[0.041]
Headquarters-Managed* Post-Broadband Introduction		-0.177	-0.230	-0.396	-0.458		-0.345	-0.415	-0.404	-0.478
		(0.099)	(0.108)	(0.187)	(0.199)		(0.121)	(0.131)	(0.218)	(0.203)
		[0.075]	[0.034]	[0.035]	[0.022]		[0.005]	[0.002]	[0.066]	[0.020]
Control Variables	No	No	Yes	No	Yes	No	No	Yes	No	Yes
Subsidiary Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Headquarters-Managed-Year Fixed Effects	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Number of Observations	3269	3269	3079	876	854	3594	3594	3366	917	885
Number of Clusters	897	897	866	257	257	911	911	879	251	251
R-squared	0.017	0.023	0.026	0.080	0.091	0.032	0.044	0.048	0.064	0.088

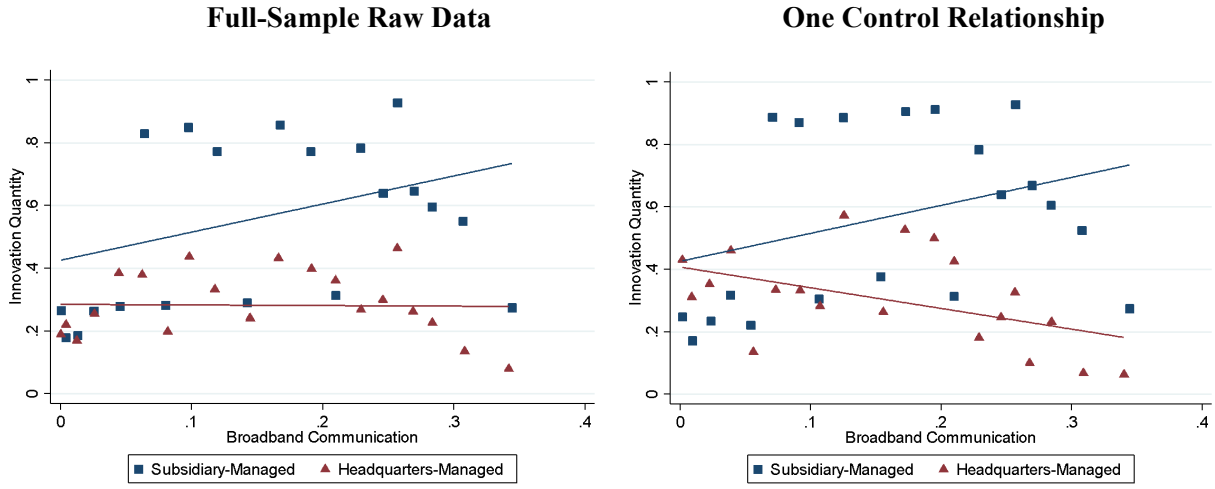
Notes. This table presents the difference-in-differences estimates of the introduction of broadband technology and innovation outcomes in columns 1 and 6. The remaining columns contain the triple difference estimates of the effect of broadband introduction on the innovation of R&D subsidiaries managed by headquarters vis-à-vis those managed by other subsidiaries. The PSM matched sample uses a vector of mean pre-treatment variables that can affect innovation outcomes. 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). Other changes in sample size are due to missing control data. 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 managing-entity country. Headquarters-Managed*Post-broadband Introduction reflects the interaction term of the binary indicator for headquarters-managed R&D subsidiary with the binary indicator for post-broadband introduction. The main effect for the binary indicator for headquarters-managed R&D subsidiary is absorbed by subsidiary fixed effects. Innovation Quality is the natural log of one plus the total number of forward citations (excluding examiner and self-citations) received by the R&D subsidiary in five years for the patents filed in the current year. Innovation Market Value is the natural log of one plus 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. 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.

Figure 1 Example of Management of R&D Subsidiaries from Representative MNE in Sample (*Within the Same MNE*)



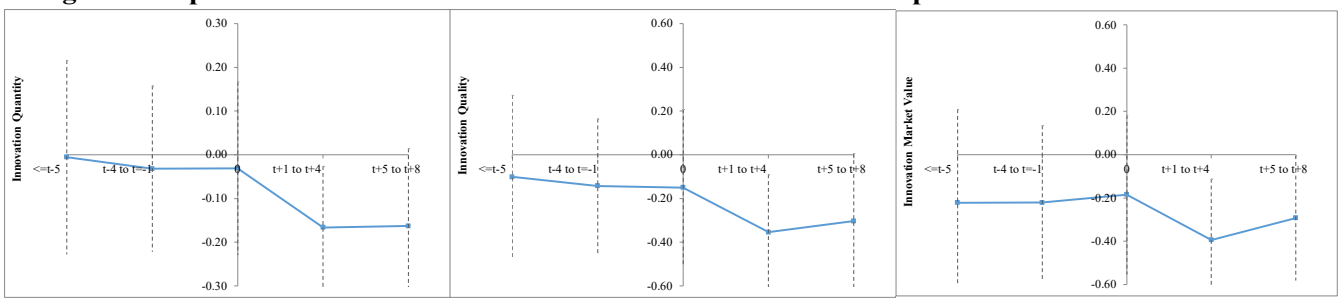
Notes. Figure 1 displays examples of subsidiary- and headquarters-managed R&D subsidiaries from a representative MNE in our sample. The MNE is headquartered in the U.S. The Swedish subsidiary manages the R&D activities of subsidiaries in Argentina, Finland, and Estonia. Headquarters manages the R&D activities of subsidiaries in Brazil, the UK, and France. As managing entities, the Swedish subsidiary and headquarters have the right to make strategic decisions on R&D projects, including selecting, funding, directing, and monitoring their R&D subsidiaries' activities. They also compensate the R&D subsidiaries for their R&D activities and hold economic ownership rights to any innovations created by the R&D subsidiaries that they manage (e.g., OECD, 2017, IRS Treas. Reg. §1.482).

Figure 2 Binscatter Plots for Innovation Output and Broadband Penetration by Managing Entity



Notes. These figures plot innovation output across the broadband penetration rate in the R&D subsidiary's location by R&D subsidiary management relationship (subsidiary versus headquarters) for 1997-2011 for the full sample (graph on the left) and the sample of R&D subsidiaries that are managed by only one MNE entity (graph on the right). Innovation output is the natural log of one plus the number of successful patents filed in a given year by the R&D subsidiary. To account for both the R&D subsidiary and the managing entity needing broadband access, each R&D subsidiary's country broadband communication value equals zero until the first year that its managing entity has at least a 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 3 Triple Differences Pre-Treatment Trends for Innovation Output



Notes. The graphs above are based on the baseline specification in Tables 6 and 11, with the Headquarters-managed*Post-Broadband Introduction split into multiple periods as indicated. Each point on the graphs represents the coefficient value of the Headquarters-managed*Post-Broadband Introduction binary indicators. The dashed lines represent the 95% confidence interval. The confidence intervals are larger in the figures than in the estimates in Tables 6 and 11 due to the reduced degrees of freedom since the Headquarters-managed*Post-Broadband Introduction variable is split into separate binary indicators for each period.