Multinational Firms and Global Innovation*

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Abstract

We examine multinational companies' (MNC) production and innovation activity to inform the globalization of innovation and its policy implications. We establish new facts for German MNCs' affiliate network and patent development worldwide, distinguish between basic and applied innovation, and introduce a patent measure of countries' revealed comparative advantage (RCA) in innovation across technology areas. The facts motivate a stylized model of heterogeneous firms that choose the locations and scale of manufacturing, applied innovation that directly lowers marginal costs, and basic innovation that improves expected future profitability. Guided by the model, we show that bigger MNCs invent more patents, at higher quality, both at home and abroad in more countries with and without affiliates. Moreover, MNCs follow countries' RCA in innovation, and more frequently co-locate applied innovation with production than basic. MNC innovation complementarity across countries lends support to multilateral deep agreements that span trade, investment and innovation policy.

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1 Introduction

Multinational companies (MNCs) are at the heart of two globalization trends: the long-standing fragmentation of production, and the recent internationalization of innovation. Much is known about MNCs' production network of affiliates and independent partners in multiple countries (Antràs and Chor, 2022). Yet while MNCs conduct the vast majority of world R&D, the location, organization and nature of their innovation activity is poorly understood (UNCTAD, 2005; Liu, 2023; Fan, 2024).

Where do multinationals develop new technologies? Do they invent in-house or subcontract to specialized labs, alongside production or not? How do they manage fundamental scientific research that fuels subsequent innovation and may thus have greater economic value (Ahmadpoor and Jones, 2017), and applied research that translates basic R&D into profitable technology upgrading? Answers to these questions inform policy debates about the impact of offshore production and innovation on domestic R&D in rich countries, as well as about promoting foreign and domestic investment in innovation in emerging economies. They are also focal to the design of trade, FDI and innovation policy in the rising number of multilateral deep agreements.[1]

Survey evidence points to evolving priorities in firms' global innovation strategy. Retaining R&D in-house to control its direction and use remains important. At the same time, MNCs are increasingly open to innovating abroad alongside production in countries with both attractive manufacturing wages and strong talent pools, as well as to collaborating with leading foreign specialists to access external expertise (Berteletti et al., 2017).[2] This departs from historic trends of western-headquartered MNCs offshoring lower-skill manufacturing to developing countries, concentrating skill-intensive R&D in-house at home, and deploying home-grown technology across their subsidiaries worldwide (Bilir and Morales, 2020). MNCs indeed increasingly innovate abroad, in both developed and emerging economies (Hall, 2011). For example, while German car maker BMW has for a long time sourced components from China, in 2018 it also unveiled a large R&D center in Shanghai to specialize in digital services, autonomous driving, and automotive design.[3] In 2017, Mercedes-Benz opened its sixth R&D lab in Seattle, primed as a digital hub for cloud computing.[4]

In this paper, we provide novel empirical evidence and theoretical rationalization for the global organization of multinational companies' innovation activity. We establish broad new facts using newly merged data on the universe of German MNCs and their patent development worldwide. We distinguish between basic (science-based) and applied (not science-based) patents, and introduce a new patent measure of countries' revealed comparative advantage (RCA) in innovation across technology areas.[5] The facts motivate a stylized model of heterogeneous firms that choose the locations and scale of manufacturing, applied innovation that directly lowers marginal costs, and

[1]For example, China's Thousand Talents Plan recruits foreign-educated and trained experts in science and technology to promote domestic innovation. World Bank data shows a steady rise in Deep Trade Agreements, with capital mobility, research and technology, and intellectual property rights among the top 10 non-trade provisions.

[2]This is consistent with an extensive interview we conducted with a German technology expert in winter 2021.

[3]BMW Corporate Communications. Press Release, 15.06.2018.

[4]Day, M. (2017, Nov 14). Mercedes-Benz plans up to 150 software engineers at Seattle R&D Office. *Seattle Times*.

[5]Throughout the paper, we study where patent inventors are located and hence where innovation takes place, rather than which patent authorities firms submit applications to and hence where they seek market protection.

basic innovation that improves expected future profitability. Guided by the model, we show that bigger MNCs invent more patents, at higher quality, both at home and abroad in more countries with and without affiliates. Moreover, MNCs follow countries' RCA in innovation, and more frequently pursue basic innovation abroad than applied, but less frequently co-locate it with production. MNC innovation complementarity across countries lends support to multilateral deep agreements that span trade, investment and innovation policy.

We match MNC data from Microdatabase Direct investment (MiDi) of Deutsche Bundesbank to patent data from PATSTAT Global of the European Patent Office for 1999-2016. This permits significantly richer analysis compared to prior studies that use data on R&D expenditure in-house at headquarters and potentially affiliates. In particular, the comprehensive patent records offer separate metrics for the quantity and quality of successful R&D. They also make it possible to differentiate between basic and applied innovation, and to identify its corresponding technology area. Finally, patent filings reveal MNCs' innovation both in countries with and without affiliates. For convenience, we nevertheless use R&D, innovation, and patent invention interchangeably below.[6]

Germany presents an ideal economic context as a top exporter, MNC origin, and innovation leader. For each German parent company, we use the location of its subsidiaries and patent inventors to identify patents developed at home, in countries with affiliates, and in countries without. We conservatively describe the latter two as innovation co-located or not co-located with an affiliate; these arguably capture respectively offshore in-house innovation alongside production and offshore subcontracted innovation.[7] We distinguish between science-based (i.e. basic) R&D that advances fundamental knowledge, and non-science-based (i.e. applied) R&D that adapts fundamental knowledge to business uses, according to patents' distance to science proxied by backward citations to science journals (Ahmadpoor and Jones, 2017). We quantify patent quality with the number of forward citations by subsequent patent applications (Hall et al., 2005).

We first establish four novel facts. First, German MNC parents frequently develop patents abroad, in countries across the income distribution, and in addition to innovating at home. This suggests that countries across the board can offer an attractive research environment, even if managing innovation at a distance is more costly. Second, MNCs often innovate in multiple locations, including both countries with and without affiliates. This points to complementarity in R&D across locations, under varying comparative advantage in innovation and production across countries. Third, basic patents are more highly cited, more frequently invented abroad, and less often co-located with production. This signals that applied R&D is less costly or more effective when proximate to production, while basic R&D is less synergistic with production and more readily subcontracted. Lastly, bigger MNCs develop both more patents and more highly cited patents. This indicates economies of scale in innovation and limited quantity-quality trade-off.

[6] See e.g., Hovhannisyan and Keller (2019); Coelli et al. (2022); Ayerst et al. (2023); Coelli (2025); LaBelle et al. (2023) for applications of patent data to study how trade and trade policy impact innovation and knowledge diffusion.

[7] Given the low affiliate size threshold in MiDi, it is unlikely that we would falsely classify in-house patent development as subcontracted in a country without a reported affiliate, but R&D may in principle be outsourced to an independent lab even in a country with an affiliate. Conversely, while we cannot rule out the presence of R&D-only subsidiaries, this is rare anecdotally and incompatible with subsidiaries' reported primary industry.

We propose that these facts are consistent with three forces driving MNC's global R&D strategy: innovation complementarity across space; asymmetric co-location complementarity between production and applied vs. basic innovation; and developed (emerging) economies having comparative advantage in innovation (manufacturing). Intuitively, a German pharmaceutical company may subcontract fundamental scientific discovery to highly-paid but essential experts in technologically advanced nations like the US or Switzerland (e.g. exploring new chemical reactions without scoping applications). At the same time, this company may pursue applied innovation alongside production in emerging economies with favorable manufacturing costs and competent technicians like China, to benefit from two-way communication between scientists and production/sales managers on site (e.g. designing new combo-vitamin packs or reducing gas dissipation in on-going manufacturing).[8]

To illustrate these mechanisms, we develop a partial-equilibrium three-country model of MNC production and innovation with potentially varying innovation costs across West (home), East and South, and cheaper production in South. We purposefully keep it stylized and focused on the innovation choice set, to build intuition and guide the empirical analysis.

In the model, heterogeneous firms choose their location(s) and scale of production, basic innovation, and applied innovation. They optimally concentrate production at a single affiliate in South due to strong economies of scale and lower manufacturing wages there. By contrast, they can pursue each innovation type at home in West, at their affiliate in South, or subcontracted to a lab in East. Innovation returns are additive across countries, with applied innovation raising profits immediately by lowering marginal production costs, and basic innovation increasing future expected profits (e.g. by facilitating future applied innovation). Site-specific innovation costs rise with innovation intensity and inventor wages, but applied innovation is less costly when co-located with production.

The model rationalizes rich MNC innovation patterns. First, more productive multinationals innovate more intensively. Second, more productive MNCs are more likely to innovate abroad and in more countries, both with and without a subsidiary there. Third, MNCs innovate more actively in countries with lower inventor wages, and, if these vary across technology classes, follow countries' comparative advantage for innovation across classes. Finally, MNCs are more likely to co-locate production with applied innovation, compared to basic innovation.

Guided by the model, we next provide novel empirical evidence for the global organization of German multinationals' innovation activity. Since MiDi does not permit MNC productivity estimation, we establish model-consistent correlations between joint outcomes of the firm problem (global sales and patent development), and exploit exogenous variation in comparative advantage for innovation across countries and technology classes within firms.

Looking across firms within sectors, we first show that larger multinational companies are more innovative, and have a more globalized innovation footprint. Bigger MNCs are more likely to file patents, and generate more patents and patent citations conditional on patenting. Larger MNCs also innovate more intensively both at home and offshore. Along the extensive margin, they have a

[8]These mechanisms align with survey evidence for 200 US and Western European MNCs on the role of R&D personnel, the preponderance of basic research in developed relative to developing countries (45% vs. 22%), and innovation abroad expanding R&D activity rather than displacing domestic R&D (75%) (Thursby and Thursby, 2006).

higher probability of innovating abroad, in more foreign countries, and both in countries with and without a subsidiary. Along the intensive margin, bigger MNCs develop more patents both at home and abroad, and have a greater share of foreign-invented patents. These patterns are quantitatively and qualitatively similar for basic and applied R&D, as well as for patent activity overall.

Looking across countries and patent technology classes within firms, we then document that MNCs respond to cross-country differences in revealed comparative advantage for innovation. We construct a new measure of time-varying innovation RCA, based on the number of patents invented in each country and technology area (by non-German firms) over 5-year non-overlapping windows. Patent activity strongly follows innovation RCA across countries and technology segments within firms, even conditioning on the presence of an affiliate as a proxy for production RCA. For example, MNCs are more likely to research IT and telecommunications in the US, measurement and medical technologies in Switzerland, and machine tools and metallurgy in Austria.

Finally, looking across individual patents within firms and technology areas, we demonstrate that MNCs are more likely to co-locate applied R&D with production, compared to basic R&D. Proximity to production is thus less important for innovation closer to fundamental science.

Our findings highlight interdependences in MNC production and innovation with important policy implications. There is complementarity between offshore production and innovation, between basic and applied innovation, and in innovation across countries. This supports national package reforms and multilateral deep agreements that span trade, investment and innovation policy, to jointly promote production fragmentation, cross-border investment and R&D. This alleviates concerns in developed countries about offshore innovation displacing domestic innovation, and reinforces incentives to attract FDI in developing countries. It also recognizes how cutting-edge research in both advanced and emerging economies can contribute to global growth, with the former leading in basic innovation, and the latter in manufacturing and synergistic applied innovation.

We contribute to several strands of literature. A large body of work has established the role of firm productivity, scale economies, and labor costs in shaping MNC production (e.g., Helpman et al., 2004; Yeaple, 2003, 2013). We incorporate these ingredients in our model of MNCs' joint production and innovation decisions, where we intentionally simplify manufacturing choices to highlight properties of the innovation strategy. Importantly, these properties would hold in more complex combinatorial choice problems with many countries or production locations (e.g., Ramondo et al., 2016; Tintelnot, 2017; Manova et al., 2025; Head et al., 2025; Castro-Vincenzi et al., 2025).

Most directly, we extend the vibrant literature on the innovation activity of multinational firms. Early studies considered R&D at parent headquarters and its deployment across the firm's network of affiliates. MNCs have been shown to earn significant returns on their home-grown innovation abroad, with host-country intellectual property rights, physical and time-zone distance driving the creation and diffusion of knowledge within the firm (Javorcik, 2004; Branstetter et al., 2006; Zhao, 2006; Keller and Yeaple, 2013; Bilir, 2014; Bilir and Morales, 2020; Bircan et al., 2021). Moreover, production offshoring can generate cost savings that incentivize innovation at home (Branstetter et al., 2021; Bernard et al., 2024).

We advance frontier research on MNC innovation *offshore*. Fan (2024) also documents that multinationals often develop patents abroad in matched Orbis-PATSTAT data. He rationalizes this in a model of product innovation, where R&D and production location are governed by costly distance, talent seeking, and market access.[9] Liu (2023) likewise explores the co-location of affiliate production and R&D by US multinationals abroad, and uses US import tariffs to identify causal effects of production (re)location on innovation. She models the dynamics of MNC production and innovation when productivity returns to R&D vary across countries and rise with co-location, and operationalizes an estimation algorithm for the implied combinatorial discrete-choice problem. Together, these two quantitative frameworks indicate that MNCs' offshore R&D generates significant welfare gains, amplifies the gains from trade, and moderates the impact of re-shoring policies. This complements estimates of welfare gains (losses) in countries with comparative advantage in innovation (in production) in earlier theory of MNC production and innovation in Arkolakis et al. (2018).

We move this agenda forward by providing novel empirical evidence and economic rationale along four dimensions. First, we consider MNC innovation in countries with and without affiliates. We rationalize why multinationals may innovate both in-house alongside production and subcontracted away from production, with complementarities across sites. Second, we distinguish between basic and applied R&D. We find organizational similarities and complementarity between the two, but also stronger synergies in co-locating applied R&D with production compared to basic R&D. Third, we establish consistent evidence for both innovation quantity and quality. We conclude that any quantity-quality trade-offs must be limited. Finally, we uncover heterogeneity in innovative capacity across countries and technology classes that goes beyond cross-country differences in talent. We show that RCA in innovation is indeed an important driver of MNC patent activity.

We also speak to the large innovation literature. Extensive research explores firms' R&D and patent activity and their impact on firm performance, innovation and exports; aggregate growth; and business dynamism (Williams, 2013; Galasso and Schankerman, 2018; Kline et al., 2019; Sampat and Williams, 2019; Farre-Mensa et al., 2020; Gong et al., 2023). This work emphasizes the greater economic value of foundational science and science-based patents compared to applied R&D (Ahmadpoor and Jones, 2017; Krieger et al., 2024). We draw on these insights to extract information on MNC innovation location, type, technology area, quantity and quality from patent data.

In turn, our work informs innovation research on firms' R&D across space and the rise in R&D activity worldwide (Hall, 2011; WIPO, 2019). Evidence shows that firms innovate in multiple domestic locations despite higher costs of managing R&D away from headquarters, with knowledge spillovers accruing across plants within a firm (Glaeser et al., 2022; Giroud et al., 2024; Chikis et al., 2025).[10] Surveys of multinational companies suggest that UK, Swiss and German MNCs collaborate with foreign inventors in advanced countries such as the US as a means of technology sourcing, especially

[9] We consider instead process innovation that improves efficiency and cost synergies from co-locating production and R&D. While our model can be augmented with both product and process innovation, the latter is sufficient to emphasize the empirically more relevant distinction between basic and applied innovation in our data: Classifying patents in a matrix of basic/applied and product/process reveals starker differences along the first dimension.

[10] Related, Fort et al. (2020) study the innovation behavior of US firms over the long run, and link the increasing importance of former manufacturing firms for US innovation to the fragmentation of production.

when highly specialized expertise is needed (Griffith et al., 2006; Gugler et al., 2010; Harhoff et al., 2014). Evidence also indicates that employing immigrant researchers, importing R&D services, and acquiring foreign firms provide alternative ways to tap global talent and benefit from reverse knowledge spillovers to headquarters (Guadalupe et al., 2012; Fan et al., 2023). We embed these insights in our analysis of the global organization of MNCs' production and innovation, by highlighting the roles of innovation type, production co-location, and countries' innovation RCA.

The rest of the paper is organized as follows. Section 2 introduces the data and novel facts about the global patent invention of German multinational firms. Section 3 develops a stylized model of MNC production and innovation that rationalizes these facts and delivers additional predictions. Section 4 provides systematic empirical evidence guided by the model. The last section concludes.

2 Data and Stylized Facts

We combine administrative firm data on German multinationals from the Microdatabase Direct investment (MiDi) of Deutsche Bundesbank with comprehensive patent data from PATSTAT Global provided by the European Patent Office (EPO). This rich matched dataset allows us to establish new stylized facts about MNCs' global production and innovation activity.

2.1 MNC Production and Innovation Data

MNC production: We characterize the global production operations of German multinational firms with comprehensive data from MiDi. MiDi covers approximately 15,000 German parents and their network of affiliates in around 200 host countries over 1999-2016.[11] German firms are legally obliged to report their foreign investments, making MiDi highly reliable.[12]

MNC innovation: We characterize MNCs' global innovation activity with detailed information on the patents they have developed from PATSTAT Global, which covers over 100 million patent documents filed with patent authorities around the world. Patents reflect the outcome of complex invention processes, and therefore provide an informative proxy for the underlying innovation effort. Patent data is both more complete than typically sparse R&D records, and rich in textual information such as the location of the inventor and various features of the patented knowledge.[13]

Firms can in principle secure property rights over a single invention or technology in multiple markets, by filing a collection of patent applications with multiple jurisdictions known as a patent family. In order to count each invention only once, we aggregate relevant data to the level of patent

[11] MiDi also comprises public and private households, which we exclude. Appendix B.1 provides more data details.

[12] See Drees et al. (2018) for a comprehensive description of the dataset. German parent firms are required to report to Bundesbank all foreign investment relationships with companies above EUR 3 mil balance sheet, that entail at least 10% direct ownership or voting rights, or at least 50% indirect or combined direct and indirect controlling stake. While MiDi tracks changes in affiliate ownership over time, ownership turnover is rare in our sample.

[13] MiDi does not cover R&D expenditures, and R&D data from alternative sources is very incomplete; it is available for roughly 7% of German patenting MNCs in Orbis. In a sample of multinationals that report R&D activity by country, Fan (2024) documents that patent counts correlate strongly with R&D expenses across countries within firms.

families, which we refer to simply as patents. We abstract away from changes in patent ownership, and study patents filed by the MNC parent of interest.[14]

We focus on patent families that include a patent filed with the European Patent Office, which we label EP patents. This follows common practice in the literature, and ensures that we compare like-for-like patent activity within a single jurisdiction - the one most relevant for German firms.[15] For completeness, we also provide summary statistics and robustness checks for the full set of patents.

We exploit the detailed bibliographical information in PATSTAT Global to categorize the innovation activity underlying each EP patent. First, we extract the technological classification of each patent so that we can compare patents within the same technology area. Second, we identify where innovation took place with the location of the patent inventors. While R&D expenditures or patent ownership may be shifted to tax havens for tax planning purposes, the inventor location is unlikely to be distorted by such motives, and thus more directly reflects where knowledge creation occurs (see also Fan, 2024). We define offshore patents as those with at least one inventor located outside of Germany. For patents with multiple inventor countries, we assign equal fractions to each one.[16]

Third, we distinguish between basic and applied patents depending on the kind of research involved. We harness each patent's *backward citations* to preceding patents and non-patent literature from the Marx and Fuegi (2020) dataset of front-page patent citations. We then measure distance to fundamental science with the minimum backward citation steps to a scientific article as in Ahmadpoor and Jones (2017). A patent that directly cites a scientific article receives a score of 1. A patent that does not itself cite a scientific article, but cites a patent that does so, receives a score of 2 because it is 2 degrees removed from science, and so on. We label patents receiving a low score of $\{1, 2\}$ as *basic (science-based)*, and patents receiving a score of at least 3 as *applied (non-science-based)*.[17]

Finally, we quantify each patent's quality with the number of *forward citations* its patent family receives. This methodology rests on the premise that innovation of higher quality enables more future innovation (Harhoff et al., 1999; Hall et al., 2005). We count the number of citations that a patent receives in subsequent patent applications to the European Patent Office, within 5 years of the first application in its patent family. This standard measure is immune to potentially heterogeneous citation practices across patent offices. The 5-year window ensures comparability in impact quality across patents filed at different times, with little data loss due to panel truncation.

Data merge & summary statistics: We build a comprehensive dataset on the global production and innovation operations of German multinationals by merging MiDi and PATSTAT based on unique firm identifiers.[18] This produces a sample of 10,155 German MNCs, roughly 30% of whom

[14] We study patent applications because those are closer to the innovation point in time than patent grants.

[15] For example, citation practices often vary across patent jurisdictions (Michel and Bettels, 2001).

[16] Among foreign-invented multi-inventor patents, approximately half have all inventors located abroad, and half have a mixed team of, on average, 1/3 inventors abroad and 2/3 in Germany.

[17] One can also differentiate between product and process innovation by relying on textual analysis of patent abstracts as in Danzer et al. (2020). We document systematic patterns in the data based on the basic-applied distinction, and find little variation of interest by further distinguishing between product and process innovation.

[18] We link MiDi to PATSTAT via the Bureau van Dijk's ORBIS database. The Deutsche Bundesbank Research and Data Center has developed a mapping from MiDi parent firms to Orbis firm identifiers (BvD ID) using supervised machine learning (Schild et al., 2017). The Bureau van Dijk in turn provides a crosswalk from Orbis to PATSTAT.

file at least one patent during 1999-2016. Our baseline regression sample includes 2,374 patenting MNCs and their 352,720 patent families, 151,227 of which are EP patents.[19]

We overlay MNCs' network of affiliates and patent development to identify innovation (i) at home, (ii) in a country with an affiliate (*offshore co-located*), and (iii) in a country with no affiliate (*offshore not co-located*). While (i) and (ii) are likely to be performed within firm boundaries, they could in principle be subcontracted to independent parties; by contrast, (iii) is arguably conducted at arm's length, as MiDi should report all foreign subsidiaries.

Panels A and B of Table 1 present summary statistics for the full matched sample and the baseline regression sample of innovative MNCs, where we retain all years that an MNC is active in MiDi as long as it appears at least once in PATSTAT. The typical parent has 4 affiliates in 3 countries, with standard deviations of 10.8 and 4.8 around these means. On average, firms generate EUR 254 mil revenues in Germany and EUR 262 mil across their foreign subsidiaries, with standard deviations of EUR 2,954 mil and EUR 2,311 mil. Innovative MNCs are generally larger in terms of parent and affiliate sales, and operate more affiliates in more host countries relative to the full sample.

Panel C reviews patent activity at the firm level. Since innovation takes time and patenting is sporadic, we report total statistics across all years a firm is active. Conditional on innovating, the average German multinational develops 149 patents and 64 EP patents during 1999-2016, with a skewed distribution and standard deviations of 1,464 and 538 respectively. The average firm files 18 basic and 45 applied EP patents, and invents 11 EP patents abroad. Patent quality varies significantly across multinationals, with a mean of 176 citations and standard deviation of 1,601.[20]

Panel D presents summary statistics at the patent level, for all EP patents in the data. Overall, 28% of MNC patents are classified as basic, and 16% as invented abroad, of which 12% in a country with an affiliate and 4% in a country without one. While the average patent attracts 2.1 citations, patent quality is generally higher for basic innovation: Basic patents receive 2.92 citations on average with a high standard deviation of 6.47, when the corresponding metrics for applied patents are 60-80% lower at 1.81 and 3.55.

Patent quality also varies across innovation locations. Offshore not co-located patents stand out with a mean citation count of 3, followed closely by offshore co-located patents with a mean of 2.7. Both outperform home-grown patents with a mean of 2 citations. This suggests that MNCs may pursue arm's length R&D in locations where they maintain no operations to tap into local expertise.

2.2 Stylized Facts

We establish four stylized facts in the matched MiDi-PATSTAT data on German multinational firms.

Fact 1: *MNCs frequently innovate abroad, in countries across the income distribution, and in addition to innovating at home.*

[19] The baseline sample does not include all firms that patent at least once because firms may appear in MiDi and PATSTAT in different years. Also, we study patents with a single owner, and drop jointly-owned patents whose innovation and filing decisions fall outside our framework. Appendix B elaborates on all other cleaning steps.

[20] We report statistics for 5-year forward citations for patents filed in 1999-2011 since the panel ends in 2016.

Table 1: Summary Statistics

Panel A. MNC production			
Sample: All German MNC (N = 10,155)			
	Firm-year level		
Variable	N	Mean	St. dev.
Parent sales, mil. €	73,800	254	2,953.8
Affiliate sales, mil. €	84,701	262	2,311.3
# affiliates	84,701	4	10.84
# host countries	84,701	3	4.78
Panel B. MNC production			
Sample: Innovating German MNC (N = 2,374)			
	Firm-year level		
Variable	N	Mean	St. dev.
Parent sales, mil. €	22,048	551	4,010.4
Affiliate sales, mil. €	25,712	397	3,549.7
# affiliates	25,712	6	14.06
# host countries	25,712	4	6.15
Panel C. MNC Innovation			
Sample: Innovating German MNC (N = 2,374)			
	Firm level		
Variable	N	Mean	St. dev.
# patents	2,374	148.58	1,464.40
# EP patents	2,374	63.70	538.20
# offshore patents	2,374	21.13	258.34
# EP offshore patents	2,374	10.74	122.84
# EP non-science-based patents (applied)	2,374	44.91	410.79
# EP science-based patents (basic)	2,374	17.59	169.18
# citations*	2,073	176.23	1,601.21
Average # citations*	2,073	1.09	1.35
Share science-based patents (EP)	2,030	0.17	0.26
Share offshore patents (EP)	2,030	0.12	0.24
Share offshore co-located (EP)	2,030	0.04	0.14
Share offshore science-based patents (EP)	2,027	0.03	0.11
Share offshore non-science-based patents (EP)	2,020	0.08	0.18

Table 1: Summary Statistics (continued)

Panel D. Patent characteristics			
Sample: EP patents			
	Patent level		
Variable	N	Mean	St. dev.
# citations	121,762	2.12	4.59
# citations, non-science based (applied)	84,957	1.81	3.55
# citations, science-based (basic)	34,504	2.92	6.47
# citations, domestic	102,029	2.00	4.09
# citations, offshore	19,733	2.76	6.58
# citations, offshore co-located	14,502	2.68	6.71
# citations, offshore not co-located	5,231	3.00	6.21
Science-based (%)	28 %		
Offshore (%)	16 %		
Offshore co-located (%)	12 %		

Notes: This table presents summary statistics for the production and innovation activity of German MNCs in 1999-2016. The sample includes all firms in Panel A, all firms that patent at least once in Panels B and C, and all EP patents in Panel D. Firm-level patent counts are aggregated across 1999-2016. 5-year forward citations are computed for 1999-2011 due to truncation. Patents are classified as basic or applied based on backward citations to scientific journal articles.
Data sources: MiDi and PATSTAT, authors' calculations.

The data reveal that 30% of all German multinational parents file one or more patents during 1999-2016. Of those, 44% develop at least one patent with an inventor located outside of Germany, and 31% at least one patent with a fully foreign-based inventor team. Almost all firms pursue research abroad in addition to domestically, with fewer than 3% conducting only offshore R&D.[21] At the patent level, 14% of all patents and 16% of all EP patents are invented abroad.

While MNCs concentrate innovation activity in major innovation hubs, they undertake significant R&D across the globe. Figure 1A plots the annual number of German MNCs developing patents in a country against its GDP per capita, averaged across 1999-2016. The United States stands out as the top location for offshore innovation by German multinationals. Technologically advanced and proximate France, Austria and Switzerland are also favored hosts. At the same time, numerous other countries across the income distribution attract non-trivial offshore innovation activity.

A similar pattern emerges when looking at the total number of German MNC patents emanating from a country over the 1999-2016 period in Figure 1B. The majority of German MNC innovation is conducted at home in Germany. Offshore R&D is common in rich, developed Western economies at the technological frontier: 19% of all offshore patents originate in the US, and another 8%, 7% and 6% in France, Austria and Switzerland respectively. Appendix Table C-1 reports snapshots of

[21] Appendix Figure C-3 groups patenting German MNCs in Orbis by their number of domestic patents. The figure confirms that MNCs that generate more patents domestically tend to also generate more patents abroad.

Figure 1: MNC Patent Activity Across Countries

Figure 1A: Number of MNCs Innovating

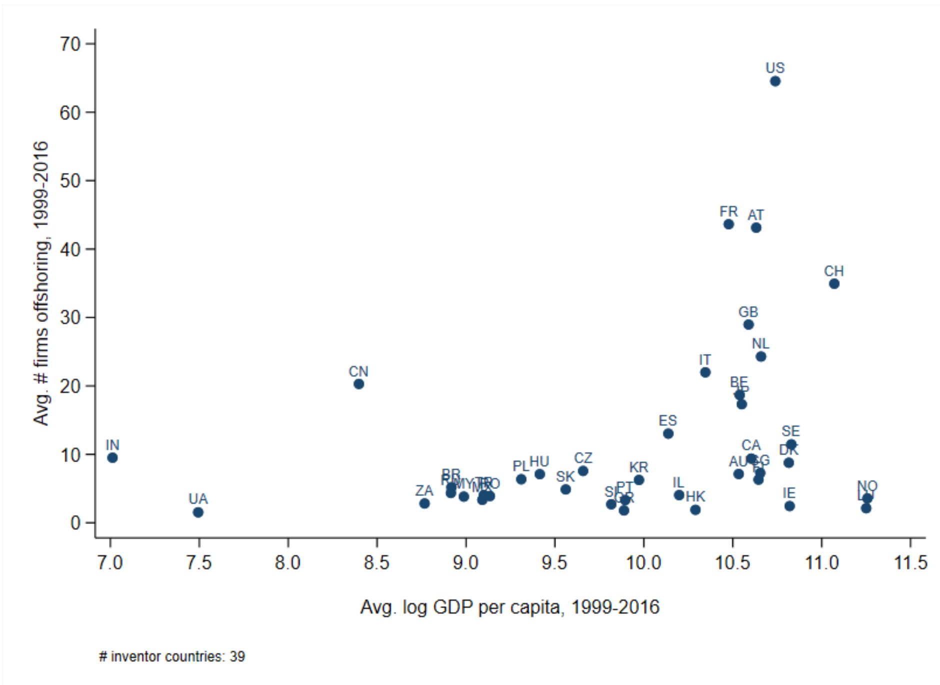


Figure 1B: Number of MNC-Invented Patents

Notes: Figures 1A and 1B plot the average annual number of German MNCs that innovate and the log number of patents invented in a given country against the country's average log GDP per capita in 1999-2016. Patents with inventors in multiple countries are assigned to each country using equal fractions. The sample comprises 40 countries hosting innovation by at least 10 MNCs. *Data sources:* MiDi, PATSTAT and World Bank National Accounts, authors' calculations.

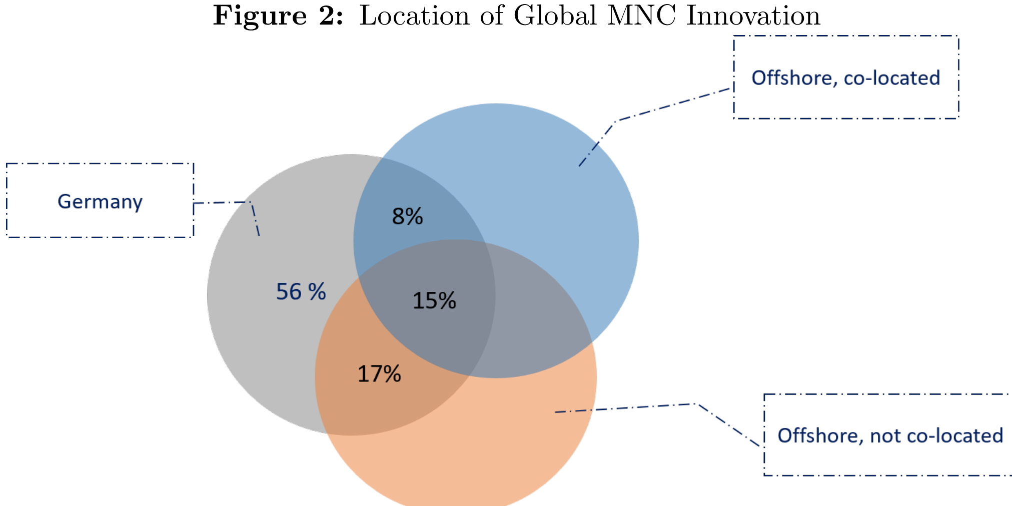
the top-5 foreign innovation hubs for 2000 and 2015.

Fact 1 raises the question why German multinational parents choose to involve foreign inventors in their innovation activities. The patterns suggest that countries across the board can offer an attractive research environment, though managing innovation at a distance may be more difficult.

Fact 2: *MNCs innovate in multiple locations, including both countries with and without affiliates.*

The Venn diagram in Figure 2 summarizes the global organization of MNC innovation, where we have collapsed activity over the 1999-2016 period to the firm level. 56% of all innovating multinational parents develop patents only at home. Some 8% conduct patent-generating innovation both at home and in another country where they operate an affiliate, while 17% do so both at home and in another country with no subsidiary. Fully 15% of firms undertake patented research in all three location types. These statistics pertain to the baseline sample of EP patents, but similar patterns obtain when considering all PATSTAT patents in Appendix Figure C-1.

Figure 2: Location of Global MNC Innovation



Notes: This Venn diagram summarizes the global organization of German MNC parent patent activity in 1999-2016. Each segment indicates the share of firms that file EP patents with inventors in Germany, offshore in a country with an affiliate, and/or offshore in a country with no affiliate. N = 2,030 firms. *Data sources:* MiDi and PATSTAT, authors' calculations.

Columns 1-3 in Table 2 provide a complementary summary of the global geography of innovation at the patent level. 83% of all EP patents filed by German multinational parents result from innovation activity within Germany. Of the patents generated abroad, 72% are invented in countries where the MNC has an affiliate, with the remaining 28% not co-located with production.[22]

Fact 2 points to complementarity in R&D activity across space, rather than research in one location displacing substitutable research elsewhere. Moreover, heterogeneous production and innovation conditions across countries may lead MNCs to pursue only one or both in a given country.

Fact 3: *MNCs' basic innovation is of greater value than applied, more frequently abroad, and more frequently in countries without affiliates.*

[22]This is consistent with Fan (2024) and Liu (2023), who find that MNC innovation offshore increases respectively with MNC sales in the host-country and with MNC imports from a country.

Table 2: Geography of MNC Global Innovation

	All EP Patents			EP basic			EP applied		
Innovation location	N	%	% within offshore	N	%	% within offshore	N	%	% within offshore
Germany	125,737	83.14		32,339	77.44		90,790	85.15	
Offshore co-located	18,473	12.22	72.47	6,532	15.64	69.34	11,871	11.13	74.99
Offshore not co-located	7,017	4.64	27.53	2,888	6.92	30.66	3,959	3.71	25.01

Notes: This table summarizes where German MNC parents invented EP patents in 1999-2016. Patents are classified as basic or applied based on backward citations to scientific journal articles. Patents can be invented in Germany, offshore in a country with an affiliate, and offshore in a country with no affiliate.
Data sources: MiDi and PATSTAT, authors' calculations.

While MNCs' basic and applied innovation generally exhibit qualitatively similar patterns, quantitatively they differ in two respects. Recall from Table 1 that basic patents receive 2.92 citations on average, compared to 1.81 citations for applied patents. This is consistent with prior evidence of patents closer to science being more valuable (Ahmadpoor and Jones, 2017; Krieger et al., 2024).

There are also geographical and organizational differences in MNCs' basic and applied innovation, as Columns 4-9 of Table 2 indicate. Relative to applied research, MNCs are disproportionately more likely to pursue basic research offshore, and to locate it in countries without an affiliate: In particular, 22.6% of all basic patents are generated abroad, of which 15.6% in a location with a subsidiary (representing 15.6/22.6=69% of offshore basic patents). In comparison, only 14.8% of all applied patents originate abroad, of which 11.1% in countries with a subsidiary (representing 11.1/14.8=75% of offshore applied patents).

Fact 3 signals that specialized international expertise may be especially relevant for complex, foundational innovation. In addition, applied R&D may be less costly or more effective when proximate to production, while basic R&D may be less synergistic with affiliate production and more readily subcontracted to independent parties.

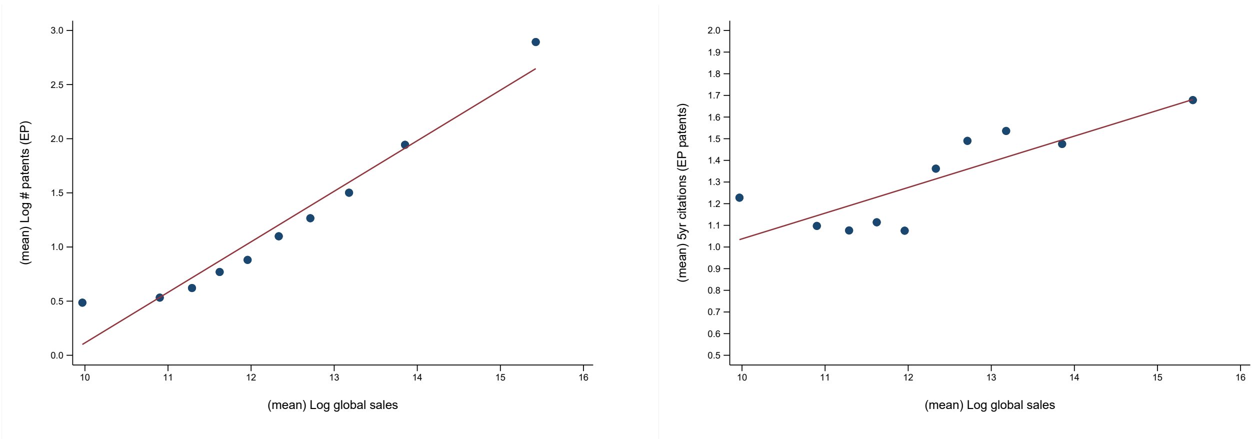
Fact 4: *Larger MNCs innovate both more intensively and at higher quality.*

Finally, the binscatters in Figure 3 indicate that bigger MNCs both invent systematically more patents and develop more highly cited patents. We assign firms into ten bins based on their annual global sales, allowing firms to move across bins over time. Figure 3A plots the log average annual number of EP patents per firm in each firm size bin. Similarly, Figure 3B shows the average number of 5-year forward citations per EP patent per firm, by size bin. We remove year fixed effects in order to account for secular trends in patent activity and citation practices. Both graphs display stark positive relationships, which Appendix Figures C-2A and C-2B replicate in the full sample of PATSTAT patents. For completeness, Appendix Figures C-4 and C-5 provide binscatters that group firms by their number of patented inventions. This confirms that MNCs that invent more patents tend to generate more cited ideas.

Fact 4 is consistent with economies of scale in innovation at the firm level. It also indicates that any quantity-quality trade-offs in research are limited enough to be dominated by scale economies.

Figure 3: MNC Size and Innovation Intensity and Quality

A Innovation Intensity **B** Innovation Quality



Notes: These binscatters plot the log average annual number of EP patents per firm in 1999–2016 and the average number of 5-year forward citations per EP patent per firm in 1999–2011, by firm size bin. German MNCs are assigned to ten bins each year according to their annual global sales. Year fixed effects are absorbed.
Data sources: MiDi and PATSTAT, authors' calculations.

3 Theoretical Framework

We next develop a model of multinational firms' global production and innovation activity that formalizes the intuitions emerging from Facts 1-4 above. We adopt a stylized, partial-equilibrium static framework in order to transparently yet tractably illustrate the key mechanisms at play.

3.1 Set-up

Consider a world comprised of three countries: West, East and South. In each country, a continuum of heterogeneous firms produce horizontally differentiated goods to sell at home and potentially also abroad. Firms can also innovate to improve their productivity and profitability.

Consumers exhibit love of variety, such that the representative consumer in country $j = \{W, E, S\}$ has CES utility $U_j = \left[\int_{i\in\Omega_j} (x_{ji})^\alpha \, di\right]^{\frac{1}{\alpha}}$, where Ω_j is the set of available goods, x_{ji} the quantity consumed of variety i, and $\sigma \equiv 1/(1-\alpha) > 1$ the elasticity of substitution across varieties, with $0 < \alpha < 1$. Demand for variety i in market j, $x_{ji} = R_j P_j^{\sigma-1} p_{ji}^{-\sigma}$, thus depends on its price p_{ji}, aggregate expenditure R_j, and the ideal price index $P_j = \left[\int_{i\in\Omega_j} (p_{ji})^{1-\sigma} \, di\right]^{\frac{1}{1-\sigma}}$.

We examine the global production and innovation decisions of firms headquartered in West (home). In each country, two types of labor engage respectively in manufacturing and in innovation. Firms take the wages of production and innovation workers, w_j and r_j, as exogenously determined in the labor market and reflecting cross-country differences in absolute and comparative advantage in production vs. innovation. We assume that $w_S < w_W$ and $w_S < w_E$, such that South has absolute advantage in production. Intuitively, West and East may have comparative (and potentially absolute) advantage in innovation, but our analysis does not rest on this assumption.[23]

3.2 Production Technology

Western entrepreneurs incur sunk entry costs associated with setting up headquarters. They face ex-ante uncertainty about their production efficiency, and draw productivity $\varphi \in (0, \infty)$ from distribution $G(\varphi)$ upon entry. Firm operations entail fixed costs of headquarter services f^H that must be performed at home. However, production can be offshored, such that the marginal cost of manufacturing in country j is w_j/φ.

Upon observing their productivity draw, firms either exit immediately or commence production and potentially become multinational and/or innovate. Western firms face a trade-off when deciding whether to locate production at home or abroad: Setting up a foreign affiliate implies additional fixed costs f^{FDI} associated with plant equipment, local management, and remote monitoring by headquarters, but it may reduce variable costs if host-country production wages are lower or if there are profitable complementarities with innovation activities.

3.3 Innovation Technology

Western firms can choose whether, where, and how much to invest in two types of innovation: basic and applied. Research can be performed at home headquarters, in-house at a foreign affiliate, and/or arm's-length at a foreign unaffiliated party. Firms can innovate in multiple locations at the same time, with innovation costs additively separable and innovation returns as specified below.

Applied innovation increases profits today and forever. Applied innovation of quality $q_j^A \geqslant 0$ improves production efficiency and lowers marginal production costs to $w_j / \left(1 + q_j^A\right) \varphi$. This is qualitatively isomorphic to applied innovation enhancing product appeal and hence demand, for example by improving product quality, marketing competence, or packaging and delivery.

Basic innovation raises the probability of higher future profits. Given an exogenous death rate δ, the present discounted value of the future stream of profits for a firm with per-period profits $\pi(\varphi)$ is $\pi(\varphi)/\delta$. We conceptualize basic innovation as higher per-period profits or lower death rate, such that basic innovation of quality $q_j^B \geqslant 0$ boosts the present value of expected profits to $\left(1 + q_j^B\right) \pi(\varphi)/\delta$. This is a reduced-form way of introducing dynamic returns to basic innovation, for instance because basic innovation is a prerequisite for subsequent successful applied innovation.

The two innovation types can be illustrated with an intuitive example: A pharmaceutical company might discover a new chemical reaction today with no concrete use (basic innovation), which might allow it to develop a new drug or more efficient production tomorrow (applied innovation).[24]

[23] While innovation wages in advanced economies might be higher than in emerging markets, they might also be lower when accounting for the quality of innovators and complementary inputs to innovation outside the model.

[24] In a richer framework, we have considered multi-product firms that can pursue applied process innovation to lower marginal production costs and applied product innovation to lower product-specific fixed production costs. Our results

Innovation incurs variable costs that increase with innovation quality, as well as fixed costs that depend on its location and organization. The cost of innovation of quality q in country j is $\mathbf{1}(q_j^{RD} > 0) r_j \left(f_j^{RD} + \frac{(q_j^{RD})^\beta}{\beta} \right)$, where $\beta > 1$, r_j is the inventor wage, $RD = \{B, A\}$ indicates the type of innovation (B = basic, A = applied), and f_j^{RD} hinges on the MNC affiliate network.

We make three assumptions on the cost structure of innovation to build conceptual understanding. First, a Western multinational cannot perform in-house innovation abroad without having first set up a production affiliate. Formally, a firm must incur the fixed subsidiary costs f^{FDI} before that subsidiary can undertake any production or innovation, and when f^{FDI} is sufficiently high, it would never be optimal to establish pure innovation subsidiaries.

Second, the fixed cost of basic innovation is higher when it is conducted abroad, but is independent of the firm's organizational structure. This captures the idea that communication, monitoring and incentive provision require more financial and managerial resources when headquarters need to supervise basic innovation at a distance and outside the firm's home jurisdiction.

Finally, a Western firm likewise faces higher fixed costs of applied innovation when it is offshore, but lower fixed costs in any given location when it is performed in-house alongside production. This reflects the scope for synergies between production and applied research that can arise from frequent interactions between production and sales managers with practical know-how, scientists with innovation talent, and technicians as two-way liaisons.

To fix ideas, take the pharmaceutical example above. The assumptions on the innovation cost function mean that a stand-alone laboratory would be equally equipped to engineer new chemical reactions as a lab at an affiliated production unit (basic innovation). By contrast, the R&D team at a manufacturing facility would be best positioned to improve production methods (e.g. reduce gas dissipation) or product design (e.g. combo-vitamin pack), because it can benefit from the knowledge of site managers and easier implementation of test runs (applied innovation).

3.4 Firm Problem

Western firms face a multi-dimensional problem: they must choose the optimal location and scale of production, basic and applied innovation to maximize global profits. The model can accommodate various patterns of MNC activity in different segments of the parameter space that govern countries' absolute and comparative advantage in production and innovation. We make two simplifying assumptions to focus on the empirically relevant case and the novel mechanisms of interest, with little loss of generality.

First, we abstract away from trade costs. Firms thus face the same global demand regardless of where they manufacture, captured by world aggregate expenditure R and price index P.

Second, we posit that economies of scale in production are sufficiently strong (i.e. fixed FDI costs f^{FDI} are sufficiently high), such that firms find it optimal to concentrate manufacturing in one location and use it as a platform from which to serve all three markets. Moreover, production wages

continue to hold, with more productive firms innovating more intensively across all innovation types and locations.

are sufficiently lower in South than in East to ensure that a Western multinational would always be incentivized to establish its single foreign subsidiary in South.

In this environment, a Western firm may choose to remain domestic and produce in-house at home. Such a firm may decide to innovate in-house at home in W, at arm's length abroad (in S and/or in E), or both. Alternatively, a Western firm may choose to become multinational and offshore all production to an affiliate in S. This multinational may innovate at home in W, abroad (in-house in S and/or at arm's length in E), or both. The country-specific fixed innovation costs it faces would satisfy $f_W^B < f_E^B = f_S^B$ for basic R&D and $f_S^A < f_W^A < f_E^A$ for applied R&D.

Firms' innovation profile can thus span multiple locations and mix in-house and arm's-length R&D. Moreover, interdependencies between production and innovation can in principle make it desirable to pursue both offshore, even if each activity alone might not be profitable abroad.

Upon entry, a Western firm will therefore determine its optimal production and innovation strategy in case it remained domestic and in case it established a foreign affiliate, and go multinational if the latter is more profitable. With fixed FDI costs, firms above a certain productivity threshold will endogenously sort into multinational activity, consistent with the prior literature.

Given our interest in MNC operations, we henceforth consider the profit maximization problem of a multinational company headquartered in West with an affiliate in South and none in East:

$$\begin{aligned}
\max_{\mathbf{G}\equiv\left\{p,x,\left\{q_j^B,q_j^A\right\}\right\}} \pi(\varphi) &= \underbrace{\left(1+\sum_j q_j^B(\varphi)\right)\left(p(\varphi)\,x(\varphi)-\frac{x(\varphi)\,w_S}{\left(1+\sum_j q_j^A(\varphi)\right)\varphi}\right)}_{\widetilde{\pi}(\varphi)} \\
&\quad \underbrace{-f^H-f^{FDI}-\sum_{RD}\sum_j \mathbf{1}\left[q_j^{RD}(\varphi)>0\right] r_j\left(f_j^{RD}+\frac{\left(q_j^{RD}(\varphi)\right)^{\beta}}{\beta}\right)}_{F(\varphi)} \\
\text{s.t.}\quad x(\varphi) &= RP^{\sigma-1}p(\varphi)^{-\sigma}.
\end{aligned} \tag{1}$$

The MNC global strategy $\mathbf{G}\equiv\left\{p,x,\left\{q_j^B,q_j^A\right\}\right\}$ is characterized by the output quantity x and price p, and a vector of 6 non-negative innovation quality levels $\left\{q_W^B,q_E^B,q_S^B,q_W^A,q_E^A,q_S^A\right\}$ for each innovation activity $RD=\{B,A\}$ in each country j. Note that innovation costs are additively separable across types and locations, but innovation returns are not: Applied innovation additively reduces marginal production costs, while basic innovation additively amplifies variable profits $\widetilde{\pi}(\varphi)$.

This complex MNC problem (1) can be solved in two steps: first determining the optimal production level and price conditional on an innovation strategy, and then identifying the optimal innovation strategy. In particular, given $\left\{q_j^B,q_j^A\right\}$, the maximization problem is isomorphic to that of a firm with exogenously set overhead costs, marginal production costs, and actuarial profit factor.

3.4.1 Optimal Production Conditional on Innovation Strategy

We first solve for MNCs' production choices conditional on its innovation activity. Under monopolistic competition and CES demand, firms optimally charge a constant mark-up $1/\alpha$ above marginal cost, and generate the following sales quantity and revenue:

$$p\left(\varphi,\{q_j^B,q_j^A\}\right)=\frac{w_S}{\alpha\left(1+\sum_j q_j^A(\varphi)\right)\varphi},\tag{2a}$$

$$x\left(\varphi,\{q_j^B,q_j^A\}\right)=RP^{\sigma-1}\alpha^{\sigma}w_S^{-\sigma}\left(1+\sum_j q_j^A(\varphi)\right)^{\sigma}\varphi^{\sigma},\tag{2b}$$

$$r\left(\varphi,\{q_j^B,q_j^A\}\right)=R\left(P\alpha/w_S\right)^{\sigma-1}\left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-1}\varphi^{\sigma-1}.\tag{2c}$$

Note that applied innovation directly enables firms to set lower prices and thereby earn higher sales and variable profits. By contrast, basic innovation does not directly affect production choices, but it may do so indirectly through the joint decision that the firm makes over basic and applied innovation. Note also that conditional on an innovation strategy, more productive firms set lower prices and earn higher sales and profits. We will see below that this advantage gets amplified by the higher innovation intensity they endogenously choose.

3.4.2 Optimal Innovation Strategy

We next solve for MNCs' optimal innovation strategy by incorporating their optimal production choices conditional on innovation from equations (2a) and (2b) into the profit equation (1):

$$\begin{aligned}\max_{\{q_j^B,q_j^A\}}\ \pi(\varphi) \quad = \quad & \underbrace{R\left(P\alpha/w_S\right)^{\sigma-1}\left(1+\sum_j q_j^B(\varphi)\right)\left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-1}\varphi^{\sigma-1}/\sigma}_{\widetilde{\pi}(\varphi)} \\ & \underbrace{-f^H-f^{FDI}-\sum_{RD}\sum_j \mathbf{1}\left[q_j^{RD}(\varphi)>0\right]r_j\left(f_j^{RD}+\frac{\left(q_j^{RD}(\varphi)\right)^{\beta}}{\beta}\right)}_{F(\varphi)}.\end{aligned}\tag{3}$$

Firms can conduct each of basic and applied R&D in any subset of countries and at varying intensity. Their global innovation strategy $\left\{q_j^B,q_j^A\right\}$ is given by the following first-order conditions:

$$\frac{\partial\pi(\varphi)}{\partial q_j^B} = 0 \Longleftrightarrow R\left(P\alpha/w_S\right)^{\sigma-1}\left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-1}\varphi^{\sigma-1}/\sigma = r_j\left(q_j^B(\varphi)\right)^{\beta-1},\ q_j^B(\varphi)\geqslant 0, \tag{4a}$$

$$\frac{\partial\pi(\varphi)}{\partial q_j^A} = 0 \Longleftrightarrow \tag{4b}$$

$$R\left(P\alpha/w_S\right)^{\sigma-1}\left(1+\sum_j q_j^B(\varphi)\right)\left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-2}\varphi^{\sigma-1}\left(\sigma-1\right)/\sigma = r_j\left(q_j^A(\varphi)\right)^{\beta-1},\ q_j^A(\varphi)\geqslant 0.$$

Although equations (4a)-(4b) don't admit closed-form solutions, they exhibit properties that inform the underlying economic mechanisms and allow us to derive comparative statics of interest.

A key feature of the firm problem is that innovation decisions will be interdependent across countries. Consider first applied innovation. From equation (4b), the optimal amount of applied innovation in any given location will depend on the global level of applied innovation. This arises because the returns to applied innovation accrue at the firm level, and manifest in lower marginal production costs regardless of where production takes place. Applied innovation will be complementary across locations if $\sigma > 2$ and $\partial^2\pi\left(\varphi\right)/\partial q_j^A \partial q_{j\prime}^A > 0$, substitutable across locations if $1 < \sigma < 2$ and $\partial^2\pi\left(\varphi\right)/\partial q_j^A \partial q_{j\prime}^A < 0$, and independent across locations in the knife-edge case of $\sigma = 2$ and $\partial^2\pi\left(\varphi\right)/\partial q_j^A \partial q_{j\prime}^A = 0$. Estimates of σ in the [3,5] range in the literature suggest that applied R&D is in practice likely complementary across countries within firms.

Equation (4b) further implies that applied innovation in any given location - and therefore also globally - will be complementary to the total and regional levels of basic innovation, $\partial^2\pi\left(\varphi\right)/\partial q_j^A \partial q_{j\prime}^B > 0$. This results from basic innovation amplifying variable profits, which rise in applied innovation. This means, for example, that any shock that encourages a firm to undertake more basic innovation will induce it to also conduct more applied innovation, and vice versa.

Consider next basic innovation. From equation (4a), optimal basic innovation in any one location does not directly depend on basic innovation elsewhere. However, it rises with total applied innovation and its components, $\partial^2\pi\left(\varphi\right)/\partial q_j^B \partial q_{j\prime}^A > 0$, which are implicit functions of global basic innovation. This generates complementarity in basic innovation across locations, $\partial^2\pi\left(\varphi\right)/\partial q_j^B \partial q_{j\prime}^B > 0$.

Finally, how much basic and applied innovation a firm performs in a given country depends on local conditions and its global levels of basic and applied innovation, but not on the geographic and implicitly organizational (in-house vs. arm's-length) composition of these global levels. In particular, while basic and applied innovation are complementary in raising operational profits, they incur additively separable costs across locations and innovation types, i.e. $\partial^2 F\left(\varphi\right)/\partial q_j^A \partial q_{j\prime}^A = \partial^2 F\left(\varphi\right)/\partial q_j^B \partial q_{j\prime}^B = \partial^2 F\left(\varphi\right)/\partial q_j^A \partial q_{j\prime}^B = 0$. Since innovation costs depend on innovation wages r_j and organizational structure, the optimal q_j^{RD} will therefore be a function of its type and location and of the total levels of applied and basic innovation, but not directly on the latter's location.

3.5 Theoretical Predictions

The integrated model of multinational firms' production and innovation delivers rich predictions for the pattern of their global operations. We focus on the novel results for MNCs' innovation strategy.

We consider first the incidence and intensity of innovation activity across firms:

Proposition 1. *More productive MNCs are more likely to innovate and to innovate more intensively.*

Proof. See Appendix A. □

More productive multinational companies will choose to innovate more for two reasons. Along the intensive margin, firm profits are supermodular in productivity and innovation, $\partial^2 \pi(\varphi) / \partial\varphi \partial q_j^B > 0$ and $\partial^2 \pi(\varphi) / \partial\varphi \partial q_j^A > 0$. Intuitively, applied innovation amplifies the advantage of more productive firms via multiplicatively lower marginal production costs, while basic innovation multiplicatively augments variable profits. Along the extensive margin, innovation entails fixed costs that more productive firms can more easily amortize because they earn higher revenues and profits. These extensive- and intensive-margin patterns hold for each of basic and applied innovation within any country and, aggregating across countries, also for innovation activity at the firm level.

We turn next to firms' optimal location and management of research and development:

Proposition 2. *More productive MNCs are more likely to innovate offshore, in more countries.*

Proof. See Appendix A. □

More productive firms will be more likely to innovate abroad in addition to at home, because of economies of scale in both production and innovation. Recall that profits are supermodular in productivity and innovation intensity, while innovation in any given location entails fixed costs. *Ceteris paribus*, there will thus be a minimum productivity cut-off $\varphi_{j,RD}^*$ above which innovation of type RD in country j becomes profitable. Since fixed costs abroad are higher than at home, this productivity threshold will tend to be higher for innovation offshore (except potentially for applied innovation at home in West vs. at the affiliate in South).

By the same logic, more productive MNCs will also be more likely to undertake research in more countries. Productivity cut-offs $\varphi_{j,RD}^*$ will generally vary across countries depending on local fixed innovation costs, local inventor wages, and model parameters that govern consumer demand and production and innovation technologies. More productive multinationals will clear the minimum threshold for more innovation locations, for each type of R&D.

Recall that we consider the innovation strategy of multinationals headquartered in West that operate a subsidiary in South only. Should they opt to innovate in both South and East, they would conduct respectively in-house and arm's-length innovation abroad. Proposition 2 thus implies the following corollary:

Corollary 1 *More productive MNCs are more likely to innovate offshore in both countries with and without affiliates.*

The model also speaks to the variation in MNC innovation activity across countries based on their comparative advantage in innovation:

Proposition 3. *MNCs are more likely to innovate and to innovate more intensively in countries with lower inventor wages.*

Proof. See Appendix A. □

Firms find it advantageous to pursue research in locations with lower inventor costs. Along the extensive margin, there is a maximum inventor wage r_j, above which innovating is not profitable because of the fixed innovation costs. Along the intensive margin, firms optimally pursue higher-quality R&D in countries with lower r_j. This can be readily observed from the first-order condition (4a) for basic innovation: The left-hand side contains only variables at the firm level, including total basic innovation, while the right-hand side increases with both r_j and $q_j^B(\varphi)$. Hence $\partial q_j^B(\varphi)/\partial r_j < 0$. The analogous result for applied innovation, $\partial q_j^A(\varphi)/\partial r_j < 0$, follows from equation (4b).

While our baseline model considers an economy with a single manufacturing sector and a single innovation sector, the analysis can be extended to a world with multiple manufacturing sectors that map to multiple innovation sectors based on the relevant technological area. If inventor wages vary both across countries and sectors, Proposition 3 would imply that innovation activity responds to countries' comparative advantage for innovation across sectors:

Corollary 2 *MNCs are more likely to innovate and to innovate more intensively in a given technological area in countries with lower inventor wages in that area.*

Finally, the model has implications for the co-location of production and innovation activities, and thereby for the internalization of innovation abroad:

Proposition 4. *Offshore applied innovation is more likely to be co-located with production than offshore basic innovation.*

Proof. See Appendix A. □

Innovation technology is such that there are synergies between applied innovation and production when performed in the same facility. In particular, the fixed costs of applied innovation are lower when it is co-located with production. All else constant, a multinational will thus find it more profitable to pursue applied R&D in countries where it operates an affiliate engaged in manufacturing.[25]

4 Empirical Evidence

The theoretical framework above can rationalize the stylized facts documented in Section 2.2 for the global organization of MNC innovation activity. Through the lens of the model, larger multinationals

[25] Cost synergies between applied innovation and production may also manifest in lower variable innovation costs, such that total applied innovation costs are $f_j^A + \mu_j^A \frac{\left(q_j^{RD}\right)^\beta}{\beta}$, where $f_S^A < f_W^A < f_E^A$ as in the baseline and $\mu_S^A < \mu_W^A = \mu_E^A = 1$. If so, both the incidence and the quality of applied innovation would be higher when co-located with production.

invent more patents at higher average quality as measured by patent citations because of economies of scale in innovation (*Fact 4*). Moreover, MNCs have an incentive to develop patents abroad in addition to at home, and in multiple countries across the income distribution where they may or may not operate an affiliate (*Facts 2 and 3*). This can be attributed to a combination of R&D complementarity across innovation sites, higher costs of managing R&D at a distance, and cross-country differences in comparative and absolute advantage for production and innovation. Lastly, firms more frequently generate applied patents in countries with a subsidiary relative to basic patents (*Fact 3*). This arises due to cost-synergies between in-house applied innovation and production at subsidiaries in countries with attractive manufacturing wages, unlike basic innovation that is advantageous in countries with an attractive research environment independent of production potential.

We now show that the model's broader predictions find strong empirical support in the global operations of German multinationals that goes beyond rationalizing *Facts 1-4*. We first establish model-consistent correlations between joint outcomes of the firm problem (global sales and patent activity) across firms. We then demonstrate that within firms, patent activity responds to exogenous variation in comparative advantage for innovation across countries and technology areas, as well as to exogenous differences in the technology for basic and applied innovation.

4.1 Estimation approach

We evaluate Propositions 1-4 and Corollaries 1-2 in the data by estimating variants of three empirical specifications at different levels of aggregation:

$$\begin{aligned} I_{ft} &= \alpha + \beta_0 \varphi_{ft} + \delta_s + \delta_t + \varepsilon_{ft}, && (5) \\ I_{fact} &= \alpha + \beta_1 \varphi_{ft} + \gamma_{RCA} RCA_{act} + \delta_a + \delta_c + \delta_t (+\delta_f) + \varepsilon_{fact}, && (6) \\ I_{fpt} &= \alpha + \beta_2 \varphi_{ft} + \gamma_{RD} D_{RD=A} + \delta_a + \delta_t (+\delta_f) + \varepsilon_{fpt}. && (7) \end{aligned}$$

We first examine the variation in innovation activity I_{ft} in the cross-section of firms f in year t with specification (5). Outcome I_{ft} reflects various aspects of patent development, such as an indicator for having any (foreign) patents, the (log) number of patents, the (log) average number of citations per patent, and the (log) number and share of foreign-invented patents. The main variable of interest on the right-hand side, φ_{ft}, is a proxy for parent-firm productivity. We condition on year fixed effects, δ_t, to absorb fluctuations in aggregate supply and demand conditions, such as changes in German production and innovation wages, tax regime, or trade and investment promotion policies. We also account for sectoral drivers of innovative activity with 23 NACE 2.0 2-digit sector fixed effects, δ_s, based on the primary industry of each parent company. These subsume, for example, cross-sector differences in factor intensities, technological scope for fragmenting and offshoring manufacturing and R&D, synergies between production and applied innovation, and innovation costs and returns more broadly. We conservatively cluster errors ε_{ft} by firm, to allow for correlated shocks within firms over time.

We follow common practice in the literature, and use (log) global firm sales as our baseline proxy for multinational firm productivity φ_{ft}. As in standard heterogeneous-firm trade models, in our framework too global firm sales are monotonic in firm productivity. The main advantage of this proxy is that it poses minimal data requirements and is not subject to potential biases in productivity estimates. In practice, while rich in many dimensions, the MiDi data on German MNCs is not sufficiently detailed to permit rigorous total factor productivity estimates.

In the model, innovation activity and total revenues are joint outcomes of the firm's profit maximization problem. We therefore interpret coefficient β_0 as a conditional correlation consistent with model predictions, rather than the causal effect of underlying productivity. We obtain robust results for (log) sales per worker at firm headquarters as an indicator of labor productivity.

In regression (6), we then unpack MNCs' patent activity to analyze how different innovation margins vary with firm size and respond to countries' comparative advantage for innovation across technology areas, RCA_{act}. Outcomes I_{fact} are now firm f's (log) number of patents and (log) number of citation-weighted patents (i.e. log total citations) in technology area a invented in country c at time t. Given the sparsity of firm patenting, we consider 3 non-overlapping 5-year periods t (2002-2006, 2007-2011, 2012-2016), and aggregate patent activity by period.[26] We map each patent to one of 34 technology areas as in Schmoch (2008), and construct countries' RCA_{act} as described below.

The main estimates of interest in specification (6) are β_1 and γ_{RCA}. Here, β_1 reflects the equilibrium correlation between firms' optimal sales and patent activity at a more granular level than in equation (5). Coefficient γ_{RCA} identifies the impact of countries' comparative advantage for innovation on the global map of MNCs' patent activity from the exogenous variation in innovation conditions across countries and technology areas. In particular, country fixed effects, δ_c, absorb cross-country differences in the overall institutional and economic environment. Year and technology area fixed effects, δ_t and δ_a, in turn account for supply and demand factors analogously to year and sector fixed effects in regression (5). More stringent specifications add firm fixed effects, to further control for persistent firm attributes that shape patent activity irrespective of technology area or inventor location. We continue to cluster errors ε_{fact} by firm.

We propose a novel measure of countries' revealed comparative advantage for innovation across technology areas, RCA_{act}. We define RCA_{act} as the number of patents generated in technology area a in country c at time t, as a share of all patents originating in that country and period. Conceptually, this measure corresponds to inventor wages in the model; in practice, it arguably captures countries' actual R&D capacity accounting for both cost and expertise. Scaling by the total number of patents ensures that the variation in RCA_{act} across countries is not driven by country size, and implicitly subsumes cross-country differences in absolute advantage in innovation.

To build RCA_{act}, we identify all patent families in PATSTAT with applications filed on three continents, i.e. with at least three of the top five patent authorities in the world. In particular, we consider patent families that include an application at the European Patent Office (EPO); the United States Patent and Trademark Office (USPTO); and either the Japan Patent Office (JPO), Korean

[26] We restrict the panel to 2002-2016 in this specification to feature three periods of equal duration.

Intellectual Property Office (KIPO), and/or China National Intellectual Property Administration (CNIPA). This ensures some degree of comparability in quality across patents, as only higher-quality inventions are generally patented in multiple jurisdictions (de Rassenfosse et al., 2013; Harhoff et al., 2003). We assign each patent to its inventor country or countries, using fractional counts as explained above.[27] To avoid circularity, we exclude patent families with German applicants.

Finally, in regression (7) we examine innovation at the most granular level of individual patents, indexed by the firm-patent-year triplet fpt. Outcome I_{fpt} is an indicator for the patent being developed in a country where the MNC operates an affiliate; this corresponds to offshore innovation being in-house alongside production in the model. We are interested in the correlation with firm size, β_1, and any systematic difference in firm choices between basic and applied patents, γ_{RD}. The latter distinction is captured by a dummy for applied patents, $D_{RD=A}$, and arguably reflects technologically exogenous differences between innovation types. Year, technology area and firm fixed effects, δ_t, δ_a and δ_f, control for firm idiosyncrasies and heterogeneous innovation conditions across time and technology areas. We once again cluster errors ε_{fpt} by firm, this time to accommodate correlated shocks to R&D across time and space within firms.

4.2 Innovation intensity

We first provide evidence that innovation activity varies systematically with total firm sales, in a way consistent with Proposition 1 that more productive firms are more likely to innovate and to innovate more intensively. To examine the extensive margin, we estimate specification (5) in the full panel of German multinationals in MiDi, where we set the outcome variable to a binary indicator for any patenting activity by firm f in year t. To evaluate the intensive margin, we then consider the log number of patents, the log number citation-weighted patents, and the average log number of citations per patent by firm-year. Conceptually, these variables can be seen as proxying the quantity and quality of innovation, respectively, which are isomorphically captured by q in the model.

Panel A of Table 3 establishes that larger MNCs pursue systematically more innovation activities. Column 1 shows that they have a significantly higher probability of filing any patents in a given year. In Columns 2-4, we further observe that bigger MNCs invent more patents that are cited more frequently on average. All coefficient estimates are highly statistically significant at the 1% level. The economic magnitudes are also sizable: The estimates imply that doubling firm sales is associated with 4 percentage points higher probability of patent-generating innovation, and, conditional on patenting, approximately 50% more patents and 2.4% more citations per patent.

Panels B and C of Table 3 confirm that larger multinationals are superior innovators within each R&D type. We repeat the regression analysis in Panel A separately for basic and applied patents, in the subsample of patenting multinationals. Since not every innovating company develops patents of both types, the number of observations varies across specifications. We find that the probability of filing any patent is an order of magnitude more sensitive to firm size for basic R&D than applied R&D. Conditional on some innovative activity, by contrast, both the frequency and the quality of

[27] Appendix B.4 elaborates on the construction of the RCA measure.

Table 3: Innovation Intensity

Dependent variable	(1) any patent (0/1)	(2) log # patents	(3) log # citation weighted patents	(4) avg log # citations
Panel A: EP patents				
Log global sales	0.039***	0.495***	0.490***	0.024***
	(0.002)	(0.027)	(0.033)	(0.004)
# MNC-years	68,999	9,545	6,180	9,545
Panel B: Basic				
Log global sales	0.101***	0.407***	0.404***	0.017*
	(0.006)	(0.037)	(0.047)	(0.007)
# MNC-years	9,007	3,986	2,543	3,986
Panel C: Applied				
Log global sales	0.019***	0.483***	0.475***	0.023***
	(0.003)	(0.028)	(0.034)	(0.004)
# MNC-years	9,007	8,217	5,227	8,217
Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: This table examines the relationship between firm sales and innovation intensity for German MNCs in 1999-2016, based on equation (5). Panel A includes the EP patents of all MNCs. Panels B and C restrict the sample to the basic and applied EP patents of patenting MNCs, respectively. Patents are classified as basic or applied based on backward citations to scientific journal articles. The outcome is an indicator for any patents in Column 1, the log number of patents in Column 2, the log number of citation-weighted patents in Column 3, and the average log number of citations per patent in Column 4. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

patenting is equally elastic with respect to firm size across the two innovation types.

While our baseline analysis covers EP patents in order to ensure patent comparability, stable results hold when we broaden the sample to consider all patents in Appendix Table D-1. Separately, we also observe qualitatively similar patterns in Appendix Table D-2 when we proxy firm productivity with the parent headquarters' log sales per employee instead of firm sales. As a caveat, some extensive-margin coefficients turn negative. We attribute this to the lack of precision of this labor productivity proxy, especially in light of how offshore production might influence employment at headquarters.

4.3 Innovation offshore

We next establish that larger multinationals are more likely to innovate abroad, to undertake innovation in more foreign countries, and to offshore a greater share of their total innovation activity.

These findings are in line with Proposition 2, and consistent with the presence of both high returns and sizable fixed costs associated with offshore R&D. In unreported results, we have confirmed that larger MNCs also develop more patents at home, and there is a positive correlation between domestic and foreign-invented patents across firms.

Table 4: Innovation Offshore

	EP patents		Basic		Applied	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Dependent variable: Any offshore patent (0/1)						
Log global sales	0.115^{***}		0.090^{***}		0.106^{***}	
	(0.005)		(0.009)		(0.006)	
# MNC-years	9,545		3,986		8,217	
Panel B. Dependent variable: share offshore patents						
Log global sales	0.018^{***}		0.017^{**}		0.017^{***}	
	(0.004)		(0.005)		(0.004)	
# MNC-years	9,545		3,986		8,217	
Panel C. Dependent variable: # foreign inventor countries						
Log global sales	0.953^{***}	0.522^{***}	0.869^{***}	0.510^{***}	0.824^{***}	0.401^{***}
	(0.208)	(0.122)	(0.212)	(0.130)	(0.216)	(0.103)
# affiliate countries		0.094^{*}		0.069^{+}		0.088^{**}
		(0.040)		(0.037)		(0.032)
# MNC-years	2,920	2,920	1,327	1,327	2,309	2,309
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table examines the relationship between firm sales and offshore innovation activity for patenting German MNCs in 1999-2016, based on equation (5). The outcome variable is an indicator for any offshore patents in Panel A, the share of offshore patents in Panel B, and the number of offshore-patent countries. The sample includes all EP patents in Columns 1-2, all basic EP patents in Columns 3-4, and all applied EP patents in Columns 5-6. Patents are classified as basic or applied based on backward citations to scientific journal articles. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

We first analyze whether a firm conducts any offshore innovation by estimating specification (5) in the panel of patenting MNCs, with an indicator for at least one patent originating abroad as the outcome of interest.[28] We present the results in Panel A of Table 4. Column 1 establishes that bigger MNCs are disproportionately more likely to file patents for inventions developed abroad. Columns 3 and 5 provide consistent evidence for offshore basic and applied patents, respectively. All estimates are highly statistically and economically significant: A doubling of global sales is associated with approximately 10 percentage points higher probability of innovation outside of Germany.

[28] As discussed earlier, we label patents as foreign-invented if at least one of its inventors resides outside of Germany.

We then consider the intensive margin of offshore innovation, and study how the share of offshore patents varies with firm size in Panel B of Table 4. Larger multinational companies do not simply scale up domestic and offshore R&D activity proportionately, but instead generate a bigger share of their patent portfolio abroad. On average, a firm double the size would develop 1.8 percentage points more of its patents abroad, as seen in Column 1. Columns 3 and 5 demonstrate that this pattern is almost identical for basic and applied patents.

Panel C of Table 4 confirms that larger MNCs offshore R&D to more countries, by setting the outcome variable in equation (5) to the number of foreign locations that firms' patents originate from. Odd columns establish this result first for all patents and then separately for basic and applied patents. A doubling of firm size corresponds to 0.8-1 more offshore inventor locations. Even columns explore the extent to which this reflects bigger multinationals operating more subsidiaries worldwide, by expanding the specification to include the number of host countries in an MNC's affiliate network. Multinationals that operate in more countries are also more likely to innovate in more countries, with a somewhat larger elasticity for applied patents than for basic patents. At the same time, while the coefficient on firm size falls by approximately 40% for basic R&D and approximately 50% for applied R&D, it remains highly significant.

Appendix Table D-3 shows that the geographic composition of MNCs' innovation activity varies systematically not only with firm size, but also with headquarters' log sales per worker, as a proxy for labor productivity. In particular, similar results emerge for the propensity for offshore R&D and the share of offshore patents across all patents and within patent type.

Through the lens of the model, these patterns are consistent with the presence of synergies between offshore innovation and production, especially for applied innovation, as well as with pull factors to undertake R&D even in locations without an affiliate, especially for basic innovation. The findings are also indicative of firms facing fixed innovation costs at the country level, which MNCs can more easily amortize if operating at a larger scale.

Finally, we evaluate Corollary 1 that bigger multinationals are more likely to pursue research both in locations with and without affiliates. To this end, we estimate a multinomial logit regression on the set of MNCs that develop patents abroad. The outcome is a categorical variable that distinguishes between three mutually exclusive strategies for offshore innovation at the firm-year level: (1) any offshore not co-located R&D (i.e. at least one patent with inventors located in a country with no affiliate), (2) any offshore co-located R&D (i.e. at least one patent with inventors located in a country with an affiliate), and (3) both co-located and not co-located offshore R&D (i.e. at least one offshore patent with inventors in each type of location). We regress this outcome variable on firm size, conditioning on year and sector fixed effects and clustering by firm as above.

The results in Columns 1-2 of Table 5 indicate that larger multinationals indeed have a greater propensity to invent patents both in countries with and without a subsidiary, compared to inventing in either location type alone. Columns 3-4 confirm that this is not driven by bigger MNCs maintaining facilities in more host countries. The analysis also reveals that among firms with a single mode of offshore R&D (either only co-located or only not co-located), larger multinationals are more likely to co-locate foreign invention with an affiliate. This pattern can be fully attributed to their greater number of subsidiary host countries. Appendix Table D-4 documents similar patterns when we instead consider firms' headquarter labor productivity (proxied by log sales per worker) in place of firm size. Of note, this measure of labor productivity drops both in magnitude and statistical significance when we condition on the number of affiliate locations. We expect this relates to the endogeneity of offshored production and employment retained at headquarters.

Table 5: Mixed Innovation Offshore

Base level: Any offshore not co-located patent	(1)	(2)	(3)	(4)
Any offshore co-located patent				
Log global sales	0.433***	0.454***	−0.019	−0.028
	(0.052)	(0.053)	(0.055)	(0.061)
# affiliate countries			0.110***	0.118***
			(0.015)	(0.017)
Both co-located and not co-located offshore patents				
Log global sales	0.663***	0.732***	0.390***	0.389***
	(0.061)	(0.069)	(0.088)	(0.095)
# affiliate countries			0.097***	0.107***
			(0.016)	(0.018)
Year FE	Yes	Yes	Yes	Yes
Sector FE	No	Yes	No	Yes
# MNC-years	2,931	2,925	2,931	2,925

Notes: This table examines the relationship between firm sales and the choice of offshore innovation locations for German MNCs with offshore EP patents in 1999-2016, based on a multinomial logit regression. The outcome variable takes value 1 if the firm invents any offshore patents in a country without an affiliate, value 2 if it invents any offshore patents in a country with an affiliate, and value 3 if it invents both co-located and not co-located offshore patents. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

4.4 Innovation comparative advantage

We next demonstrate that MNC patent activity responds to cross-country differences in revealed comparative advantage for innovation across technology areas, RCA_{act}, as per Proposition 3 and Corollary 2. In particular, firms develop systematically more patents and receive more patent citations in countries with strong RCA_{act} within a given technology area.

To explore this pattern, we estimate specification (6) at the firm-technology area-country-period level, using the log number of patents and the log number of citation-weighted patents as the outcomes of interest. We view the latter as a more comprehensive measure of the quality-weighted extent of innovation activity. When aggregating to this level of analysis, each patent is assigned to a single technology area and, if relevant, split equally among inventor countries as explained above.

Table 6A presents robust evidence that economies with stronger RCA_{act} in a given technology field attract significantly more innovation activity by German multinationals in that field. Columns 1 and 4 establish this baseline result conditioning on a full set of country, technology area, and period fixed effects, such that the main coefficient of interest is identified from the variation in comparative advantage within a country across technology areas and within an area across countries. Our findings reinforce the talent-seeking motive for offshore innovation emphasized by Fan (2024), and signal that not only country-level talent, but also field-specific expertise is important for innovation location.

Table 6A: Innovation Comparative Advantage

Dependent variable	log # patents			log # cit. weighted patents		
	(1)	(2)	(3)	(4)	(5)	(6)
RCA	0.014***	0.017***	0.023***	0.018**	0.023***	0.027***
	(0.004)	(0.004)	(0.004)	(0.006)	(0.006)	(0.007)
Avg. log global sales		0.094***			0.117***	
		(0.021)			(0.018)	
Affiliate country = 1			0.122***			0.068
			(0.032)			(0.064)
Observations	8,741	7,762	7,475	4,970	4,404	4,167
Tech area FE	Yes	Yes	No	Yes	Yes	No
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	Yes	No	No	Yes

Notes: This table examines the relationship between countries' revealed comparative advantage for innovation across technology areas and offshore innovation activity by German MNCs, based on equation (6). Data is aggregated into three non-overlapping five-year periods (2002-2006, 2007-2011, 2012-2016). The outcome is the log number of patents in Columns 1-3, and the log number of citation-weighted patents in Columns 4-6. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

We next establish that countries' comparative advantage for innovation shapes the allocation of offshore R&D even within firms across space. In Columns 2 and 5, we condition on firm size. In Columns 3 and 6, we add a full set of MNC firm fixed effects, and control for the presence of a subsidiary in the country. These regressions account for the variation in innovation with firm characteristics, as well as for potential benefits from co-locating production and innovation. The impact of RCA_{act} remains highly statistically significant, and its magnitude is largest under the most stringent specification with firm fixed effects. The estimates suggest that a unit increase in RCA_{act} would attract 2% more of a firm's patents in that country and technology area.

Table 6B confirms that MNCs respond to cross-country difference in innovation potential for each of basic and applied R&D. We replicate the analysis in Table 6A separately for basic and applied patents in firms' portfolio. We consistently observe that countries' revealed comparative advantage is a strong driver of MNCs' offshore patent activity within each type of R&D.

Table 6B: Innovation Comparative Advantage: Patent Type

Panel A: Basic R&D						
Dependent variable	log # patents			log # cit. weighted patents		
	(1)	(2)	(3)	(4)	(5)	(6)
RCA	0.009^{+}	0.014^{**}	0.022^{***}	0.013^{*}	0.019^{**}	0.026^{**}
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.008)
Avg. log global sales		0.084^{***}			0.110^{***}	
		(0.015)			(0.020)	
Affiliate country = 1			0.104^{*}			0.016
			(0.041)			(0.076)
Observations	4,005	3,677	3,535	2,490	2,279	2,156
Panel B: Applied R&D						
Dependent variable	log # patents			log # cit. weighted patents		
	(1)	(2)	(3)	(4)	(5)	(6)
RCA	0.013^{**}	0.014^{**}	0.019^{***}	0.018^{*}	0.025^{**}	0.026^{**}
	(0.005)	(0.005)	(0.005)	(0.008)	(0.009)	(0.009)
Avg. log global sales		0.082^{**}			0.104^{***}	
		(0.027)			(0.018)	
Affiliate country = 1			0.106^{*}			0.077
			(0.042)			(0.070)
Observations	5,968	5,343	5,050	3,126	2,785	2,567
Tech area FE	Yes	Yes	No	Yes	Yes	No
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	Yes	No	No	Yes

Notes: Table 6B replicates the analysis in Table 6A separately for basic patents in Panel A and applied patents in Panel B. Patents are classified as basic or applied based on backward citations to scientific journal articles.
Data sources: MiDi and PATSTAT, authors' calculations.

In unreported results, we observe similar patterns using an alternative measure of RCA_{act} that captures the variation in a country's innovation propensity across technology areas, relative to the cross-area variation for the world as a whole. In particular, we scale the share of patents in a technology area in all patents invented in a country by the corresponding global share of that technology area in all patents invented worldwide. The two alternative RCA_{act} measures have a highly statistically significant positive correlation of 0.77.

We refrain from using metrics of absolute technological advantage such as the number of patents per technology area and country, because such measures are strongly positively correlated with GDP. Results may therefore reflect the impact of market size or income rather than innovation potential.

4.5 Innovation co-location

We conclude by assessing multinationals' strategy with respect to co-locating foreign production and innovation activities in line with Proposition 4. Fan (2024) and Liu (2023) find that offshore production and offshore innovation are positively correlated. We document that conditional on offshore innovation, firms are systematically more likely to co-locate applied R&D with an affiliate than basic R&D. This is consistent with proximity to manufacturing experience being more synergistic with applied innovation, for instance if close interactions between production managers and scientists can enable cheaper and more effective applied research.

Table 7: Innovation Co-location

	co-located offshore patent (0/1)			
	(1)	(2)	(3)	(4)
Non-science-based patent (0/1)			0.039**	0.013*
			(0.015)	(0.006)
Log global sales	0.113***	0.111***	0.113***	0.111***
	(0.008)	(0.026)	(0.008)	(0.026)
Tech. area FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	No	Yes	No	Yes
# patents	21,997	21,765	21,997	21,765

Notes: This table examines the propensity of German MNCs to co-locate offshore basic and applied innovation with an affiliate in 1999-2016, based on equation (7). Patents are classified as basic or applied based on backward citations to scientific journal articles. The outcome is an indicator for a patent being invented in a country where the MNC has an affiliate. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

We analyze co-location strategies by estimating equation (7) at the patent level in Table 7. For each patent, we construct a binary outcome variable equal to 1 if it is developed in a country where the MNC operates an affiliate. Columns 1-2 first confirm that larger multinationals are more likely to develop new technologies in host countries with an active subsidiary. This result is in line with the implication of Proposition 2 and Corollary 1 that more productive firms are more likely to innovate in multiple locations, including countries with an affiliate. Columns 3-4 then establish that even controlling for firm size, MNCs are systematically more likely to co-locate applied innovation with an affiliate than basic innovation. These relationships remain highly statistically significant even in stringent specifications that exploit the variation across patents and countries within firms by conditioning on firm fixed effects.

5 Conclusion

Multinational companies play a central role in both global value chains and frontier R&D. We provide one of the first integrated analyses of MNCs' global production and innovation strategy. We establish novel stylized facts using rich data on the network of affiliates and patent development of German multinationals. We rationalize these facts with a heterogeneous-firm model in which companies jointly choose the location, scale and integration of manufacturing, basic innovation and applied innovation. Empirical evidence consistent with the model indicates that more productive MNCs innovate more intensively in terms of the number and quality of patents. Such companies also invent patents in more countries, spanning both countries with and without affiliates. Finally, MNC innovation efforts follow countries' comparative advantage across technology areas, with applied R&D more likely to be co-located with production than basic R&D.

Our findings open the door to various avenues for future research. Richer information on the inputs and outputs of innovation activity, such as data on both R&D investment and successful patenting, can provide a more holistic understanding of the factors governing MNC operations. Also of interest is the role of intellectual property rights protection and general contract enforcement for the location and integration of MNC production and innovation.

It is likewise important to evaluate the implications of MNCs' globalized production and innovation for the design of trade and innovation policy. This will inform the scope for multilateral agreements, especially as developed and developing countries occupy different segments of global value chains and engage differently in technological innovation and adoption. For example, our work points to complementarity rather than substitutability in innovation activity across countries, which may alleviate concerns about the impact of offshore innovation on sending economies. MNC operations may also shape the impact of technological leaps such as automation on the global distribution of production, innovation and adoption, and thereby on economic growth across countries. Lastly, the interaction of home-grown R&D entrepreneurship and knowledge spillovers from MNC R&D in emerging economies may inform global growth prospects and multilateral growth policies.

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Appendix

A Theoretical appendix

Proof of Proposition 1. Firm profits $\pi(\varphi)$ are supermodular in productivity and innovation quality.

Intensive margin:

$$\frac{\partial^2 \pi(\varphi)}{\partial q_j^A \partial \varphi} = R\left(\frac{\alpha P}{w_s}\right)^{\sigma-1} \frac{(\sigma-1)^2}{\sigma} \left(1+\sum_j q_j^B(\varphi)\right)\left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-2} \varphi^{\sigma-2} > 0, \quad \text{and}$$

$$\frac{\partial^2 \pi(\varphi)}{\partial q_j^B \partial \varphi} = R\left(\frac{\alpha P}{w_s}\right)^{\sigma-1} \frac{(\sigma-1)}{\sigma} \left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-1} \varphi^{\sigma-2} > 0, \quad \text{and further}$$

$$\frac{\partial^2 \pi(\varphi)}{\partial q_j^A \partial q_j^B} = R\left(\frac{\alpha P}{w_s}\right)^{\sigma-1} (\sigma-1) \left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-2} \frac{\varphi^{\sigma-1}}{\sigma} > 0. \qquad \square$$

Extensive margin: As profits are increasing and supermodular in innovation quality and productivity, more productive firms are more likely to amortize the fixed costs of innovation for every innovation type and location.

Proof of Proposition 2. Follows from Proposition 1, the ranking of fixed costs of innovation, and the assumption that fixed costs have to be paid for each country.

Proof of Proposition 3. Firm profits $\pi(\varphi)$ are submodular in inventor wages and innovation quality.

Intensive margin:

$$\frac{\partial^2 \pi(\varphi)}{\partial q_j^A \partial r_j} = -\sum_j \mathbf{1}(q_j^A > 0)(q_j^A(\varphi))^{\beta-1} < 0, \quad \text{and}$$

$$\frac{\partial^2 \pi(\varphi)}{\partial q_j^B \partial r_j} = -\sum_j \mathbf{1}(q_j^B > 0)(q_j^B(\varphi))^{\beta-1} < 0, \quad \text{and further}$$

$$\frac{\partial^2 \pi(\varphi)}{\partial q_j^A \partial q_j^B} = R\left(\frac{\alpha P}{w_s}\right)^{\sigma-1} (\sigma-1) \left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-2} \frac{\varphi^{\sigma-1}}{\sigma} > 0. \qquad \square$$

Extensive margin: Result follows from intensive margin result along with profits being increasing in innovation qualities.

Proof of Proposition 4. Follows from ranking of fixed costs: Fixed costs of applied innovation are strictly lower when co-located with production. Fixed costs of basic innovation are independent of a firm's organizational structure, so applied innovation is *ceteris paribus* more likely to be co-located with production than basic innovation.

B Data Construction

B.1 Microdatabase Direct investment (MiDi)

This paper uses foreign direct investment administrative data on German multinational firms from the Microdatabase Direct investment (MiDi) maintained by the Deutsche Bundesbank.[29] This database contains annual German outward and inward FDI information starting for the period 1999-2016. Since we are interested in the global network of affiliates of German multinational firms, we limit our analysis to firms reporting outward direct investments. MiDi contains information at the individual investment relationship level and both direct and indirect investment relationships between a German parent company and its foreign subsidiaries are included.

Based on the German Foreign Trade and Payments (*Aussenwirtschaftsverordnung*) decree, German companies are required to report information regarding their foreign direct investments to the Deutsche Bundesbank if they:

- own directly at least 10 % of the shares (or voting rights) in a foreign company that has a balance sheet total above EUR 3 mil.
- own a combined controlling share of more than 50% in a foreign company with a balance sheet total above EUR 3 mil (either indirectly or through a combination of direct and indirect shares).

These reporting rules have been in place since 2007, after two main historical changes in 2002 and 2007. For our analysis, we take into account firms that were not affected by changes in the reporting requirements over time, i.e. firms that meet all reporting requirements during 1999-2016. Following this strategy, we implicitly remove all firms that voluntarily report to the German Bundesbank, without being required to. Additionally, we remove all public or private households that fall under the reporting requirements. Given that firms are legally bound to report information regarding their foreign operations, MiDi contains highly reliable, "close to complete" data (Drees et al., 2018).

In this paper, we are primarily interested in the location of German MNCs' foreign affiliates such that we construct an annual mapping of their global operations. In addition, we use both parent and affiliate turnover information in order to construct our main productivity proxy, global sales. For this computation, we weight each affiliate's turnover by the parent's total participation in the firm. As a robustness check, we compute an alternative productivity proxy, parent sales per employee.

Our main outcomes of interest relate to firms' patenting activity. Therefore, the construction of our baseline sample of German MNCs requires a linkage between MiDi and patent data obtained from PATSTAT Global. In absence of a direct link between MiDi parent firms and patent applicants in PATSTAT, we rely on information from Bureau van Dijk's Orbis dataset. The Deutsche Bundesbank

[29] This paper uses the 2018 version of the MiDi database. DOI: 10.12757/Bbk.MiDi.9916.04.05. See Drees et al. (2018) for detailed information on the database.

Research and Data Center has developed a mapping from MiDi parent firms to Orbis firm identifiers (BvD ID) using supervised machine learning (see Schild et al., 2017). Through a crosswalk from Orbis (version 2016) to PATSTAT, we are able to link the two databases of interest. We retrieve the firms' primary industry of activity in the 2-digit NACE 2.0 classification from Orbis as well. Therefore, our baseline sample of MNCs comprises parent firms with at least one foreign affiliate active in MiDi that is also captured in Orbis, such that we are able to assess whether they had filed any patents in the period of interest.

B.2 PATSTAT

In order to analyze firms' patenting activity, we retrieve all patents filed during 1999-2016 by the MNCs in our baseline sample from PATSTAT Global (version autumn 2018). In our analysis, our focus remains on the patents that are filed by the parent firms in our baseline sample, abstracting from patents originating from firms' affiliates alone. The reason for this is twofold: first, the data available does not allow us to link firms' foreign affiliates in MiDi with patent applicants in PATSTAT. Second, affiliate innovation strategies could be influenced by local market characteristics which could lead to systematic differences in the patents that are filed by affiliates relative to the parent firms. Different intellectual property strategies of affiliates and parents may also introduce systematic differences in the type or quality of the patents filed. We further restrict our sample to patents that have only a unique MNC owner. Therefore, we remove co-inventions across multiple MNCs that would involve strategic decisions that go beyond our paper. However, note that our sample would still include patents that have other applicants outside of the sample of MNCs that we observe.

We group all patent filings originating from our baseline firms into patent families. A patent family is a collection of patent applications that are filed across multiple jurisdictions but that essentially cover a single invention or technology. Throughout the analysis, we avoid multiple counting of the same invention by using DOCDB patent families instead of single applications. For each patent family, we determine the year of the first patent filing within the family, as the closest point in time to the development of the invention. Additionally, for each patent family, we identify the main technological area among the 34 areas proposed by Schmoch (2008). We choose the technology area that is most common across all filings in the patent family. Whenever a mode cannot be identified, we select the main technological area of the first filing within the family. We drop patent families that do not contain any application that represents a patented invention, i.e. we remove families that only contain utility models or design patents. By EP patents we refer to patent families that contain an EP application (European patent application filed at the European Patent Office). We measure patent quality by summing up all EP patent citations each focal patent family received within a 5-year window since the first filing date. We count forward citations originating from the EP applications in order to maintain comparability, as citation patterns vary systematically across patent offices.

We obtain inventor information from the latest publication document of each patent application retrieved from PATSTAT. Since inventor information can be incomplete across applications within the same family, we develop an algorithm such that we harmonize information at the DOCDB family level. Specifically, we prioritize information from applications filed at the European Patent Office, at the United States Patent and Trademark Office, German Patent and Trademark Office (DPMA) and the World Intellectual Property Organization, as they would be the most likely to contain complete information. We separated patent families that contain at least one of the applications above and those that do not. For each group in turn we take the following cleaning steps: (1) we count the number of inventors for each application and compute the number of inventors where country information is missing, (2) we identify the application with the lowest number of inventors with country information missing and is also the earliest within the family. For each patent family, we retrieve the inventor location information from this identified application. We remove patents for which we cannot identify the inventor location.

Once we combine data on affiliate location in MiDi with inventor countries in PATSTAT, we are able to distinguish between:

- **domestic patents**: all inventors are located in Germany
- **offshore patents**: at least one inventor is located abroad
  - **offshore *co-located* patents**: at least one of the foreign inventor countries match with an affiliate country (affiliates active in the same year as the patent filing year)
  - **offshore *not co-located* patents**: none of the foreign inventor countries match any of the affiliate countries (affiliates active in the same year as the patent filing year)

B.3 Patent type: science-based and non-science-based patents

We distinguish between two different patent types as proxies for firms' applied and basic R&D activities. We do so by using patents' distance to science following Ahmadpoor and Jones (2017). Specifically, we assume that a patent with a short distance to a scientific article would result from basic R&D activities. We define these as science-based patents. Alternatively, patents that are more distant from fundamental science are associated with applied R&D activities and labeled as non-science-based patents.

We construct the distance to science measure for EP patent applications included in our baseline sample. We restrict our attention to applications filed only in one patent office to ensure comparability, given that citing patterns differ across offices. We retrieve backward citations for all applications of interest from PATSTAT Global. Additionally, we link all focal patents and their corresponding patent citations with the *Reliance on Science* open-access dataset provided by Marx and Fuegi (2020). This includes patent front-page citations to scientific articles retrieved from Microsoft Academic Graph and PubMed.

Patents that directly cite a scientific article receive a distance to science score of 1. For the remaining patents, we consequently check whether their cited patents in turn cite a scientific article. We repeat this step until we are able to establish how many degrees distant the focal patents are from scientific articles. Therefore, our measure produces a score of $\{1, 2, 3, ...\}$, with lower scores indicating a more closer connection to fundamental science. We label patents receiving a score of $\{1, 2\}$ as *science-based* and patents receiving a score of at least 3 as *non-science-based*.

B.4 Revealed comparative advantage in innovation measure

We propose a measure of countries' revealed comparative advantage (RCA) in innovation that captures countries' capacity to enable innovation that results in patent filings. We define country's c revealed comparative advantage in technology area a and year t as:

$$RCA_{act} = \frac{\#PAT_{act}}{\sum_a \#PAT_{act}} \times 100,$$

where $\#PAT_{act}$ represents the total number of patents in technology area a in year t that originate in country c. We scale by the total number of patents invented in country c in the same year in order to account for country size. The measure allows us to identify the technology areas where countries have most expertise.

We retrieve the full set of international patent families available in PATSTAT Global (version spring 2021 [30]) that contain at least one application filed at three of the top five leading patent authorities in the world. These include the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO) and the China National Intellectual Property Administration (CNIPA). Hence, we consider patent families that include at least one application at the EPO, one at the USPTO and an additional one at either JPO, KIPO or CNIPA. Using this definition allows us to generate a comparable measure across countries that is not affected by countries' different patent filing propensities. Additionally, only higher-quality inventions are patented in multiple jurisdictions. Firms would only seek protection in a larger geographical region and in turn, incur the higher patent filing costs that come with that decision for higher quality inventions. We exclude all patent families that have German applicants in constructing our measure. Ideally, we would have excluded only the patents filed by the German MNCs included in our analysis so that we ensure that our measure does not capture patenting decisions of the firms we are interested in. However, due to confidentiality rules at the Research Data and Service Center of the Deutsche Bundesbank, we have no way to link the MNCs and PATSTAT outside of the research center. Therefore, we took the more conservative approach of removing all patents that have a German applicant among those we select for constructing the RCA measure. We retrieve inventor information for all patents of interest and follow the same cleaning steps as mentioned in Appendix B.2. We assign each patent to its inventor

[30] This is the only part of the analysis that relies on a different PATSTAT version. We do so in order to capture the complete 1999-2016 period. Due to lags in the patenting process via the international route (PCT), where it can take up to 32 months from the first patent application to subsequent filings, our original PATSTAT Global (v. autumn 2018) would have included truncated data for the last years of interest. See Dechezleprêtre et al. (2017) for a discussion on international patent families.

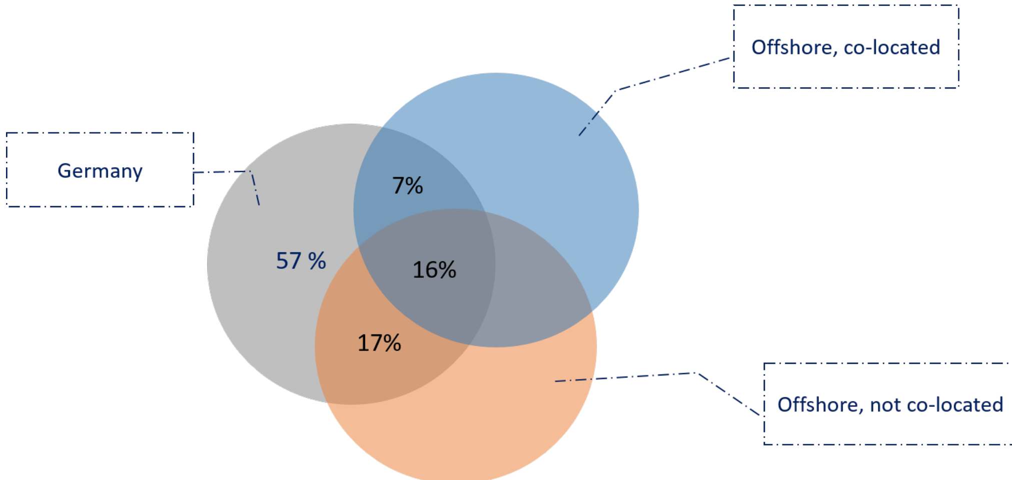
countries using fractional counts as explained above.

In robustness analyses, we compute an alternative measure of revealed comparative advantage in innovation of a country, defined as:

$$altRCA_{act} = \frac{\frac{\#PAT_{act}}{\sum_a \#PAT_{act}}}{\frac{\sum_c \#PAT_{act}}{\sum_a \sum_c \#PAT_{act}}}$$

C Additional descriptives

Figure C-1: Location of Global MNC Innovation: All Patents



Notes: This Venn diagram summarizes the global organization of German MNC parent patent activity in 1999-2016. Each segment indicates the share of firms that file patents with inventors in Germany, offshore in a country with an affiliate, and/or offshore in a country with no affiliate. N = 2,374 MNCs. *Data sources:* MiDi and PATSTAT, authors' calculations.

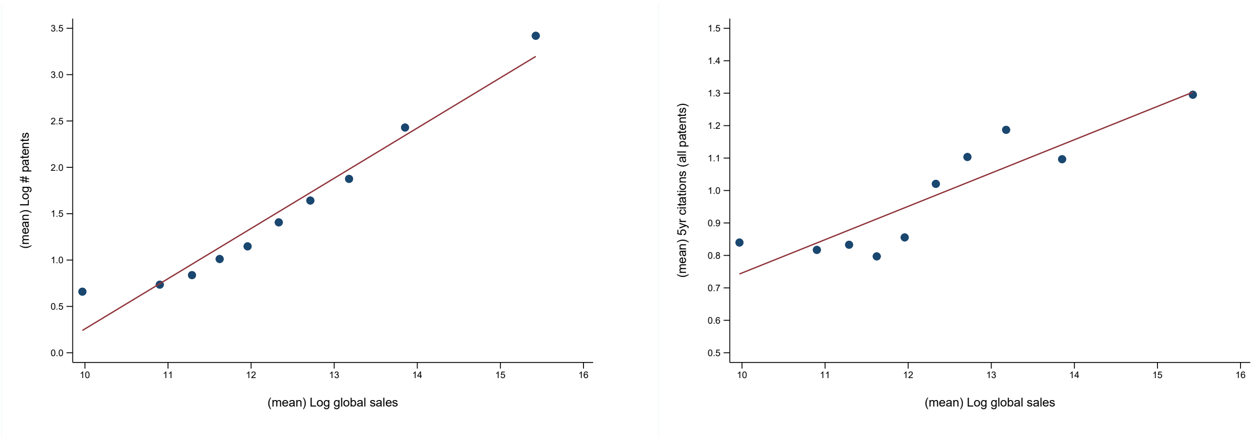
Table C-1: Top Foreign Innovation Hubs for German MNCs

	Overall, 1999-2016		2000		2015	
	Country	% offshore patents	Country	% offshore patents	Country	% offshore patents
1	US	19.2 %	US	33.2 %	US	16.6 %
2	FR	8.0 %	AT	9.1 %	AT	7.6 %
3	AT	6.9 %	FR	7.2 %	FR	6.0 %
4	CH	5.2 %	CH	5.1 %	IT	5.0 %
5	IT	4.0 %	JP	3.5 %	CN	4.9 %

Notes: This table lists the top-5 foreign countries where German MNCs invent patents by patent counts. Fractional counts are used for patents with multiple inventor countries.
Data sources: MiDi and PATSTAT, authors' calculations.

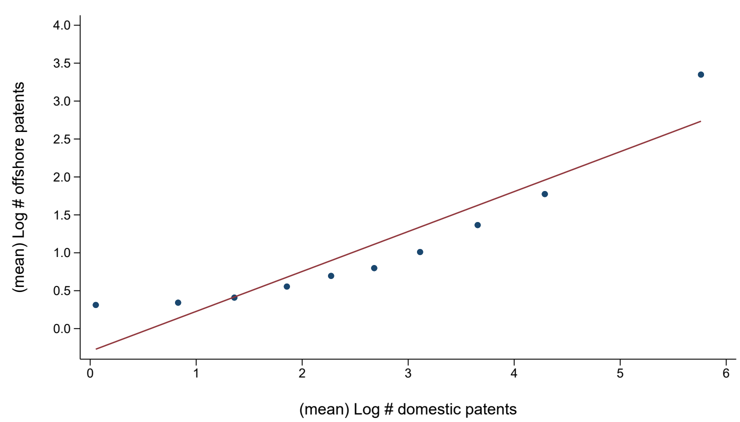
Figure C-2: MNC Size and Innovation Intensity and Quality: All patents

A Innovation Intensity **B** Innovation Quality



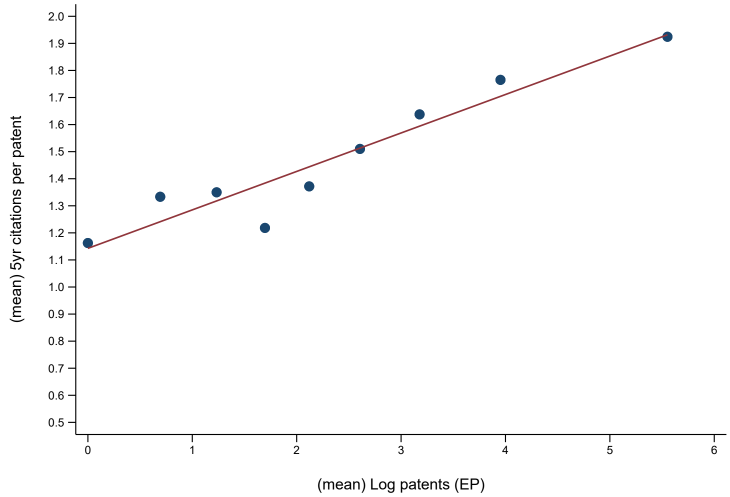
Notes: These binscatters plot the log average annual number of all patents per firm in 1999–2016 and the average number of 5-year forward citations per patent per firm in 1999–2011, by firm size bin. German MNCs are assigned to ten bins each year according to their annual global sales. Year fixed effects are absorbed.
Data sources: MiDi and PATSTAT, authors' calculations.

Figure C-3: Innovation Intensity at Home and Abroad: All patents



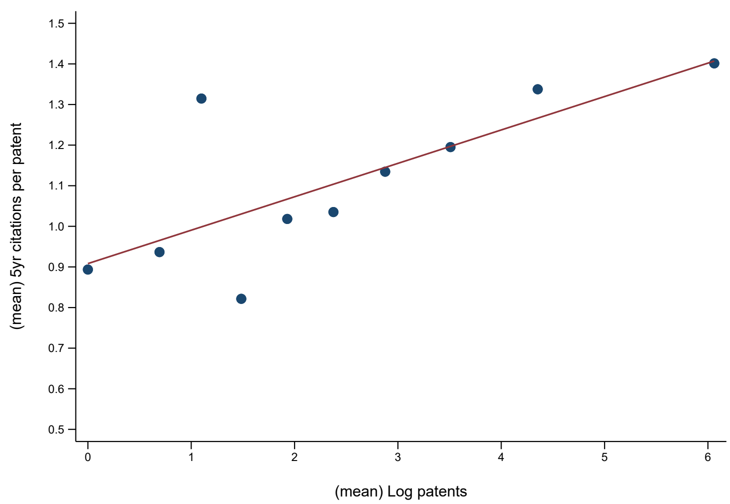
Notes: This binscatter plots the log average annual number of offshore patents per firm in 1999-2011, by firm domestic patent intensity bin. German MNCs are assigned to ten bins each year according to their annual number of domestic patents. Year fixed effects are absorbed.
Data sources: Orbis and PATSTAT, authors' calculations.

Figure C-4: Innovation Intensity and Quality Across MNCs: EP patents



Notes: This binscatter plots the average number of 5-year forward citations per EP patent per firm in 1999-2011, by firm patent intensity bin. German MNCs are assigned to ten bins each year according to their annual number of EP patents. Year fixed effects are absorbed.
Data sources: MiDi and PATSTAT, authors' calculations.

Figure C-5: Innovation Intensity and Quality Across MNCs: All Patents



Notes: This binscatter plots the average number of 5-year forward citations per patent per firm in 1999-2011, by firm patent intensity bin. German MNCs are assigned to ten bins each year according to their annual number of patents. Year fixed effects are absorbed.
Data sources: MiDi and PATSTAT, authors' calculations.

D Robustness checks

Table D-1: Innovation Intensity: All Patents

Dependent variable	(1) any patent (0/1)	(2) log # patents	(3) log # citation weighted patents	(4) avg log # citations
Log global sales	0.040***	0.567***	0.553***	0.022***
	(0.002)	(0.029)	(0.031)	(0.004)
# MNC-years	68,999	11,837	7,329	11,837
Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: This table examines the relationship between firm sales and innovation intensity for German MNCs in 1999-2016, based on equation (5). The sample includes all patents of all MNCs. The outcome is an indicator for any patents in Column 1, the log number of patents in Column 2, the log number of citation-weighted patents in Column 3, and the average log number of citations per patent in Column 4. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

Table D-2: Innovation Intensity: Robustness

Dependent variable	(1) any patent (0/1)	(2) log # patents	(3) log # citation weighted patents	(4) avg log # citations
Panel A1: All patents				
Log domestic sales/employees	-0.021^{***}	0.192^{***}	0.241^{***}	0.029^{***}
	(0.004)	(0.047)	(0.058)	(0.008)
# MNC-years	40,680	11,202	6,944	11,202
Panel A2: EP patents				
Log domestic sales/employees	-0.013^{***}	0.173^{***}	0.228^{***}	0.029^{**}
	(0.003)	(0.043)	(0.058)	(0.010)
# MNC-years	40,680	9,047	5,858	9,047
Panel B: Basic				
Log domestic sales/employees	0.054^{***}	0.201^{**}	0.243^{*}	0.022
	(0.012)	(0.065)	(0.095)	(0.015)
# MNC-years	8,555	3,796	2,423	3,796
Panel C: Applied				
Log domestic sales/employees	-0.002	0.148^{***}	0.184^{***}	0.031^{**}
	(0.007)	(0.040)	(0.051)	(0.010)
# MNC-years	8,555	7,820	4,968	7,820
Sector FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: This table examines the relationship between headquarters' labor productivity and innovation intensity for German MNCs in 1999-2016, based on equation (5). Panels A1 and A2 include all patents or all EP patents of all MNCs, respectively. Panels B and C restrict the sample to the basic and applied EP patents of patenting MNCs, respectively. Patents are classified into basic and applied based on backward citations to scientific journal articles. The outcome is an indicator for any patents in Column 1, the log number of patents in Column 2, the log number of citation-weighted patents in Column 3, and the average log number of citations per patent in Column 4. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

Table D-3: Innovation Offshore: Robustness

	EP patents		Basic		Applied	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Dependent variable: Any offshore patent (0/1)						
Log (domestic sales/employees)	0.054***		0.067***		0.049***	
	(0.012)		(0.018)		(0.013)	
# MNC-years	9,047		3,796		7,820	
Panel B. Dependent variable: share offshore patents						
Log (domestic sales/employees)	0.025***		0.037***		0.018**	
	(0.007)		(0.011)		(0.007)	
# MNC-years	9,047		3,796		7,820	
Panel C. Dependent variable: # foreign inventor countries						
Log (domestic sales/employees)	0.309	0.132	0.445+	0.317	0.176	0.005
	(0.199)	(0.214)	(0.228)	(0.253)	(0.144)	(0.124)
# affiliate countries		0.149***		0.115**		0.131***
		(0.040)		(0.037)		(0.036)
# MNC-years	2,746	2,746	1,251	1,251	2,175	2,175
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table examines the relationship between headquarters' labor productivity and offshore innovation activity for patenting German MNCs in 1999-2016, based on equation (5). The outcome variable is an indicator for any offshore patents in Panel A, the share of offshore patents in Panel B, and the number of offshore-patent countries. The sample includes all EP patents in Columns 1-2, all basic EP patents in Columns 3-4, and all applied EP patents in Columns 5-6. Patents are classified into basic and applied based on backward citations to scientific journal articles. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.

Table D-4: Mixed Innovation Offshore: Robustness

Base level: Any offshore not co-located patent				
	(1)	(2)	(3)	(4)
Any offshore co-located patent				
Log (domestic sales/employees)	0.251*	0.242*	0.050	0.122
	(0.098)	(0.096)	(0.089)	(0.090)
# affiliate countries			0.127***	0.135***
			(0.016)	(0.018)
Both co-located and not co-located offshore patents				
Log (domestic sales/employees)	0.421**	0.365*	0.239	0.247
	(0.140)	(0.149)	(0.155)	(0.164)
# affiliate countries			0.127***	0.137***
			(0.016)	(0.018)
Year FE	Yes	Yes	Yes	Yes
Sector FE	No	Yes	No	Yes
# MNC-years	2,756	2,750	2,756	2,750

Notes: This table examines the relationship between headquarters' labor productivity and the choice of offshore innovation locations for German MNCs with offshore EP patents in 1999-2016, based on a multinomial logit regression. The outcome variable takes value 1 if the firm invents any offshore patents in a country without an affiliate, value 2 if it invents any offshore patents in a country with an affiliate, and value 3 if it invents both co-located and not co-located offshore patents. Standard errors clustered by firm. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Data sources: MiDi and PATSTAT, authors' calculations.