Multinational Firms and Global Innovation*

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Abstract

This paper provides an integrated analysis of multinational companies' global production and innovation. We establish novel stylized facts using rich data on the network of production affiliates and patent activity of German multinationals. We rationalize these facts with a heterogeneous-firm model, in which companies jointly determine the location and scale of production, basic innovation and applied innovation, under asymmetric complementarities across these three activities. Empirical evidence consistent with the model indicates that bigger MNCs innovate more intensively in terms of patent frequency and quality, and offshore innovation to more countries, including both countries with and without production affiliates. Moreover, MNCs' innovation portfolio follows countries' comparative advantage across technology classes, with applied innovation more likely to be co-located with production than basic innovation.

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1 Introduction

Multinational companies (MNCs) are at the heart of two key globalization trends: the fragmentation of production chains and the internationalization of technological progress. MNCs are focal in global value chains (GVCs), in that they manage complex production networks across multiple countries and offshore manufacturing stages to both foreign affiliates and independent parties. At the same time, MNCs are also responsible for the vast majority of frontier R&D and cross-border technology transfer. These phenomena have first-order implications for the optimal design of trade and innovation policy in developed and developing countries. They 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.

While a large literature examines the global organization of MNC production, relatively little is known about the global organization of MNC innovation. Traditional priors might suggest that MNCs headquartered in rich countries retain skill-intensive activities at home and offshore low-skill intensive manufacturing to poorer countries. Yet anecdotal evidence points to increasing offshoring of innovation, to both advanced and emerging economies. For example, while leading German car producer BMW has for a long time sourced auto components from China, in 2018 it also unveiled a large research and development center in Shanghai to specialize in digital services, autonomous driving, and automotive design.[1] In 2017, Mercedez-Benz opened its sixth R&D lab in Seattle, primed as a digital hub for cloud computing.[2]

This paper provides an integrated analysis of MNCs' global production and innovation. We establish novel stylized facts using uniquely rich data on the network of production affiliates and patenting activity of German multinationals.[3] We rationalize these facts with a heterogeneous-firm model, in which companies jointly determine the location and scale of production, basic innovation and applied innovation, under asymmetric complementarities across these three activities. Empirical evidence consistent with the model indicates that bigger MNCs innovate more intensively in terms of patent frequency and quality. Such companies also offshore a greater share of their innovation and to more countries, including both countries with and without production affiliates. Moreover, MNCs' innovation portfolio follows countries' comparative advantage across technology classes, with applied R&D more likely to be co-located with production than basic R&D.

Our first contribution is to uncover new facts about the global innovation activity of multinational companies. We obtain firm-level data on German MNCs and their worldwide network of production affiliates from the Microdatabase Direct investment (MiDi) of the Deutsche Bundesbank, and match it to patent-level data from PATSTAT Global maintained by the European Patent Office. For each parent company, we use the location of its subsidiaries and patent inventors to identify innovation conducted at the headquarter country, offshored to a country with an affiliate, or offshored to a country without an affiliate. We conceptually distinguish between basic R&D that advances

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

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

[3] We use "patenting", "innovation" and "R&D" interchangeably throughout the paper for expositional convenience.

fundamental knowledge and applied R&D that adapts fundamental knowledge to production uses. In particular, we classify patents into basic (or science-based) and applied (or non-science-based) according to their distance to fundamental science, as proxied by backward citations to scientific articles (Ahmadpoor and Jones, 2017). We also quantify patent quality with the number of forward citations by subsequent patent applications (Hall et al., 2005).

We establish three stylized facts about MNCs' patent-generating research and development. First, MNCs innovate actively and frequently abroad. Second, MNCs innovate in multiple locations, and offshore innovation to locations both with and without affiliates. Third, larger MNCs innovate at higher intensity and quality. Germany provides an ideal economic context to study these patterns, as it is the third biggest exporter, a top MNC origin, and a world innovation leader.

Our second contribution is to develop a partial-equilibrium three-country model of MNCs' global production and innovation strategy, motivated by the new stylized facts. In the model, heterogeneous firms jointly choose the location and scale of their output production, basic innovation, and applied innovation to maximize total profits. Firms optimally operate a single manufacturing facility due to economies of scale in production. Each type of R&D may or may not be offshored, to one or multiple countries, with or without a production affiliate in the same location. The returns to innovation are additive across countries within an innovation type and multiplicative across innovation types, with basic innovation increasing future expected profits and applied innovation raising profits immediately by lowering marginal production costs. Site-specific innovation costs are higher abroad, and rise with innovation intensity and local inventor wages. Importantly, there are cost synergies between production and applied R&D, but not with respect to basic R&D. This setup generates complementarities in innovation across types and locations.

This model delivers several key predictions. First, more productive multinationals are more likely to innovate and to innovate more intensively. Second, more productive MNCs are more likely to offshore R&D and to undertake R&D in more countries. Given the geographic concentration of production, this also implies that more productive MNCs have a greater propensity to simultaneously pursue innovation both in locations with and without a manufacturing subsidiary. Third, MNCs are more likely to innovate and to innovate more intensively in countries with lower inventor wages. When inventor wages also vary across technology areas, MNCs locate innovation activity according to countries' comparative advantage. Finally, MNCs are more likely to conduct applied innovation in locations where they operate a production affiliate, compared to basic innovation.

Our third contribution is to provide systematic empirical evidence for the operations of German multinationals that is consistent with the model's predictions. In the absence of direct productivity measures and innovation data, we use global firm sales and observed patent outcomes as model-consistent proxies.

We first confirm that bigger MNCs are more likely to file patents. Conditional on patenting activity, bigger MNCs generate more patents, record more total patent citations, and receive more citations per patent on average. Moreover, these patterns hold for each of basic and applied R&D.

We then establish that larger firms are more likely to offshore innovation. We proxy offshore innovation using patents that have at least one inventor located abroad. Along the extensive margin, bigger MNCs have a higher probability of innovating in at least one foreign country. Along the intensive margin, bigger MNCs develop a greater share of their patented technologies abroad. Larger firms also innovate in more countries on average, and are more likely to pursue R&D both in locations with and without a production subsidiary. Once again, all of these findings hold both with respect to total innovation activity and separately within each innovation type.

We next document that MNCs respond to cross-country differences in comparative advantage in innovation across technological fields. We construct an indicator of revealed comparative advantage in innovation at the country-technology area level, based on the total number of patents invented in each country and technology class (excluding patents invented by German firms). We observe that even within a multinational firm, the pattern of inventor location across countries and technology segments strongly follows comparative advantage, particularly when we consider citation-weighted patent counts.

Lastly, we demonstrate that multinationals are more likely to co-locate applied R&D with production, compared to basic R&D. Non-science-based patents are more likely to be offshored to countries where the MNC operates a production affiliate, compared to science-based patents that are closer to fundamental science.

Our paper advances several strands of literature. At a broad level, we add to a large body of work on the drivers of multinational production activity. Extensive theoretical and empirical analysis has found that firm productivity, cross-country differences in production wages, and economies of scale at both the firm and establishment level are key determinants of MNC production patterns (Helpman et al., 2004; Yeaple, 2003, 2013). We incorporate these ingredients in a generalized model of the joint production and innovation decisions of multinational firms. We purposefully keep manufacturing choices stylized to highlight the novel interdependence of innovation decisions across locations, as well as between manufacturing and innovation. Our framework can, however, be readily enriched to incorporate more complex production strategies across countries that recent contributions explore (Ramondo et al., 2016; Tintelnot, 2017).

We also extend a separate literature on the innovation activity of multinational firms. This line of work traditionally examines R&D at the parent headquarters and its deployment across the firm's affiliate network and consumer markets through production technologies and product design. Evidence indicates that intellectual property rights protection matters for multinationals' production and sales decisions (Javorcik, 2004; Branstetter et al., 2006; Bilir, 2014). MNC parents nevertheless earn significant returns on their home-grown innovation abroad, with time-zone differences shaping the creation and diffusion of knowledge within the firm (Bilir and Morales, 2020; Bircan et al., 2021). Moreover, improved opportunities for production offshoring can generate cost savings that incentivize innovation at headquarters (Branstetter et al., 2021; Bernard et al., 2024).

We advance this agenda in three dimensions. First, we consider MNCs' global production and global innovation strategy in an integrated framework. We examine offshore innovation to both locations with and without production affiliates, uncover important distinctions between basic and applied innovation, and study their different cost synergies with production. In closely related work, Liu (2023) focuses specifically on the benefits of co-locating production and generic innovation in a structural dynamic model of MNC investments, to evaluate the impact of re-shoring policies.[4] Second, we exploit novel margins of MNC patent data, distinguishing between basic and applied innovation. And third, our work provides empirical context for recent models that quantify the welfare impact of MNC operations under innovation either by the parent or by both parent and affiliate (Arkolakis et al., 2018; Fan, 2021).

Finally, we leverage insights from the innovation literature, and in the process draw bridges between growth and innovation on the one hand and multinational activity on the other. Prior research has typically focused on domestic innovation and its links to firm performance, business dynamism, and aggregate growth. An active area of work explores patent activity and the impact of patent grants on subsequent firm performance, innovation, and exporting (Williams, 2013; Galasso and Schankerman, 2018; Kline et al., 2019; Sampat and Williams, 2019; Farre-Mensa et al., 2020; Gong et al., 2023). It has in particular emphasized the distinction between basic and applied innovation, the importance of foundational science for private-sector innovation, and the greater economic value of science-based patents (Ahmadpoor and Jones, 2017; Krieger et al., 2023). Our paper adds a new angle to this literature by exploring the globalization of innovation and multinational patent activity.

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

2 Data and Stylized Facts

We first establish new stylized facts about the global production and innovation activity of multinational firms using uniquely rich data for Germany.

2.1 MNC Production and Innovation Data

We combine administrative firm-level data on German multinational firms from Microdatabase Direct investment (MiDi) of Deutsche Bundesbank (German Central Bank) with rich patent-level data from PATSTAT Global, the worldwide patent database provided by the European Patent Office.

MNC production. We characterize the domestic and foreign production operations of German multinational firms with comprehensive data from MiDi. MiDi covers approximately 15,000 German parents and their global network of affiliates in around 200 host countries over 1999-2016.[5] Since

[4]In a domestic context, 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.

[5]MiDi also comprises private and public households. We exclude those from our analysis. More details on data construction can be found in Appendix B.1.

German parent firms are legally obliged to report their foreign investments, MiDi offers high-quality information from the accounting statements of each parent and each subsidiary that is comparable across countries (e.g. sales, employment, total assets, country location, industry affiliation).[6]

Panel A of Table 1 summarizes the substantial variation in multinational production activity across firms and over time. On average, a German parent has 4 affiliates in 3 countries, with standard deviations of 10.8 and 4.8 around these means. The typical multinational generates EUR 254 mil worth of sales revenue at its headquarters and EUR 262 mil across its foreign affiliates, with standard deviations of EUR 2,954 mil and EUR 2,311 mil respectively.

MNC innovation. We characterize MNCs' global innovation activity with detailed information on the patents they hold from PATSTAT Global, a database that contains detailed bibliographical data on over 100 million patent documents filed with patent authorities around the world. Patents reflect the outcome of complex invention processes, and therefore provide an imperfect, but informative proxy for the underlying innovation effort.[7] Patent data is not only more complete than typically sparse R&D records, but it also contains additional detailed information such as the location of the inventor and the nature of the patented knowledge.

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 families, which we refer to simply as patents. We abstract away from changes in patent ownership, and focus strictly on patents filed by the MNC of interest.

We restrict the baseline analysis to patent families that include a patent filed with the European Patent Office (EPO), which we label EP patents. This follows common practice in the literature, and ensures that we compare like-for-like patenting activity within a single jurisdiction - the one most relevant for German firms.[8] It also allows us to exploit additional information about patent types as explained below. For completeness, we provide summary statistics and robustness checks for the full set of firm patents in PATSTAT Global.

We build a comprehensive matched dataset on the global production and innovation operations of German multinationals by merging MiDi and PATSTAT based on unique firm identifiers.[9] This produces a sample of 10,155 German MNCs, roughly 30% of whom file at least one patent within the 1999-2016 time frame. Our baseline regression sample includes 2,374 patenting MNCs and their 352,720 patent families.[10] Of these, 151,227 patents include an application filed with the EPO.

[6]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.

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

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

[9]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.

[10]The baseline matched sample does not include all 30% of firms that patent at least once for several reasons. First,

Table 1: Summary Statistics

Panel A. MNC production

Sample: All German MNC (N = 10,155)

Variable	N	Mean	St. dev.
	Firm-year level		
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)

Variable	N	Mean	St. dev.
	Firm-year level		
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)

Variable	N	Mean	St. dev.
	Firm level		
# 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 German MNCs in Panel A, all German MNCs that patent at least once in Panels B and C, and all EP patents by German MNCs in Panel D. Firm-level patent counts are aggregated across all years in 1999-2016. 5-year forward citation counts are computed for the restricted 1999-2011 period to account for truncation. Patents are classified into basic (science-based) and applied (non-science-based) based on backward citations to scientific journal articles.
Data sources: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Panel B of Table 1 presents summary statistics for the baseline sample of German MNCs that hold at least one patent, where we retain all years that an MNC is active in MiDi as long as it appears at least once in PATSTAT. Innovating MNCs are not only larger in terms of parent and affiliate sales on average, but are also present in more host countries and have more foreign affiliates relative to the full sample in Panel A.

We use information on the location of the patent inventors to identify where the underlying innovation activity took place. For patents with multiple inventor countries, we assign equal fractions to each one. We define offshore patents as those with at least one inventor located outside of Germany.

While German MNCs' innovation activity is highly concentrated in major innovation hubs, MNCs undertake significant patent-generating R&D across the globe. Figure 1A plots the average yearly number of MNCs developing patents in a given country against the country's GDP per capita. The United States stands out as the top location for offshore innovation by German multinationals. France, Austria and Switzerland - technologically advanced and proximate countries - are also favored

a firm may appear in MiDi and in PATSTAT in different years, i.e. it may patent in a year with no corresponding MiDi entry. Second, we focus on patents with a single MNC owner, and drop jointly-owned patents whose innovation and filing decisions may reflect economic forces beyond the scope of this paper. Appendix B elaborates on all other cleaning steps in building the baseline patent sample.

Figure 1: MNC Patent Activity Across Countries

Figure 1A: Number of MNCs Innovating

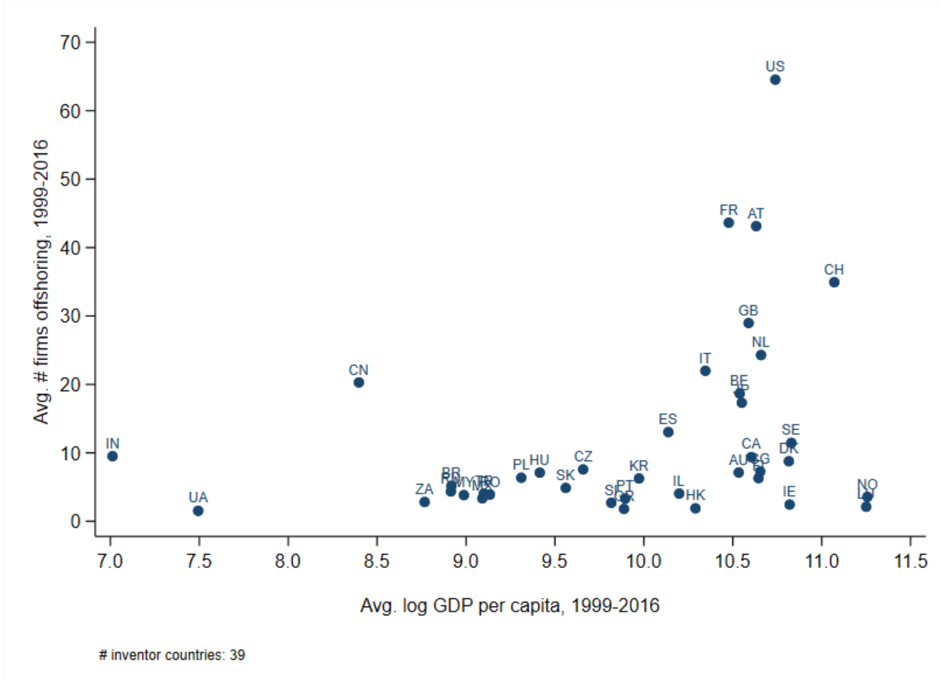


Figure 1B: Number of MNC-Invented Patents

Notes: Figures 1A and 1B plot the average annual number of German MNCs that innovate and the log total number of patents invented in a given country against the country's average log GDP per capita in 1999-2016. Patents with inventors from multiple locations are assigned to each country using equal fractions. The sample comprises 39 countries hosting innovation by at least 10 MNCs.

Data sources: Research Data and Service Center of the Deutsche Bundesbank (MiDi), PATSTAT and World Bank National Accounts, authors' calculations.

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 patents emanating from an inventor 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 concentrated in rich, developed Western economies at the technological frontier, with the top hubs the same as in Figure 1A. Over the entire period, 19% of all offshore patents originate in the US, whereas France, Austria and Switzerland contribute 8%, 7% and 6%, respectively. Appendix Table C-1 illustrates the overall top-5 foreign innovation hub ranking, together with snapshots for 2000 and 2015.

We distinguish between three types of MNC innovation locations, by combining information on the network of production affiliates and patent inventors: (i) at home in the headquarter country, (ii) offshore co-located, i.e. in a country with an affiliate present, and (iii) offshore not co-located, i.e. in a third country with no affiliate present.[11]

Patent characteristics. PATSTAT Global contains detailed bibliographical data that extends beyond patents' applicants, inventors, and underlying invention. In particular, each patent file records the technological classification of the patented technology, preceding patents and non-patent literature the patent application cites (*backward citations*), and subsequent patents that cite it (*forward citations*). Drawing on techniques from the innovation literature, we exploit this information to categorize the type of innovation activity underlying each EP patent and to evaluate its quality.

We distinguish between two types of patents depending on the kind of research firms have engaged in: basic (or science-based) and applied (or non-science-based). In particular, we follow Ahmadpoor and Jones (2017) to measure a patent's distance to fundamental science with the minimum backward citation steps to a scientific article, using the Marx and Fuegi (2020) open-access dataset of patent front-page citations. 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. This measure thus produces a score of $\{1, 2, 3, ...\}$, with lower scores indicating a more proximate 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*. Since these two patent types conceptually result from basic and applied R&D, respectively, we also interchangeably use the labels *basic* patent and *applied* patent for expositional simplicity.[12]

We also quantify each patent's innovation quality with the number of forward patent citations its patent family receives. This methodology follows common practice in the literature, and rests on the premise that innovation of higher quality acts as a stepping stone for more subsequent innovation activity (Harhoff et al., 1999; Hall et al., 2005). We count the number of citations that a patent

[11] Intuitively, (i) and (ii) are likely to be performed within firm boundaries, although they could in principle be subcontracted to independent parties in locations with MNC presence. On the other hand, (iii) is unlikely to be performed in-house, as any foreign subsidiary of relevant size should be visible in MiDi.

[12] 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.

receives in subsequent patent applications filed with the European Patent Office, in the 5 years after the first application within its patent family. This standard measure is immune to potentially heterogeneous citation practices across patent offices. It also ensures comparability in impact quality across patents filed at different times, with little data loss due to panel truncation.

Panel C of Table 1 provides an overview of patent activity at the firm level in the matched MiDi-PATSTAT baseline dataset. Since innovation can be time-consuming and patenting sporadic, we collapse the time dimension and aggregate across all years a firm is active in the panel. On average, a patenting German multinational generates roughly 148 patents and 64 EP patents over the 1999-2016 period, where the distribution is extremely skewed with standard deviations of 1,464 and 538 respectively. On average, firms apply for 18 science-based and 45 non-science-based EP patents, and hold 11 EP patents with at least one inventor located abroad. There is significant variation in patent quality across multinationals, with the mean number of citations a firm receives standing at 176 and its standard deviation reaching 1,601.[13]

Panel D of Table 1 presents summary statistics at the patent level. Overall, 28% of all EP patents are classified as science-based and 16% are developed abroad, of which 12% in a country with a foreign production affiliate and 4% in a country with no subsidiary. While the average patent attracts 2.1 citations, by this measure, patent quality is generally higher for basic innovation: While science-based patents receive 2.92 citations on average with a high standard deviation of 6.47, the corresponding metrics for non-science-based patents are about 50% lower at 1.81 and 3.55. This is in line with prior evidence consistent with patents closer to science being more valuable (Ahmadpoor and Jones, 2017; Krieger et al., 2023). At the same time, patent quality also appears to vary 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 notably outperform home-grown patents with a mean of only 2 citations. This suggests that MNCs may offshore R&D to locations where they maintain no production operations to tap into specific local knowledge and expertise that allow them to develop valuable inventions.

2.2 Stylized Facts

The matched MiDi-PATSTAT database is unique in painting a comprehensive picture of the global innovation activity of multinational firms. We begin by establishing three novel stylized facts that emerge from this data.

Fact 1: *MNCs innovate actively and frequently abroad.*

The data reveal that 30% of all German multinational companies file one or more patents during 1999-2016. Of those, 43% develop at least one patent with a foreign inventor located outside of Germany, and 31% at least one patent with a fully foreign-based inventor team.[14] At the patent

[13] We report statistics for 5-year forward citations for patents filed in 1999-2011 to avoid truncation bias as the panel ends in 2016.

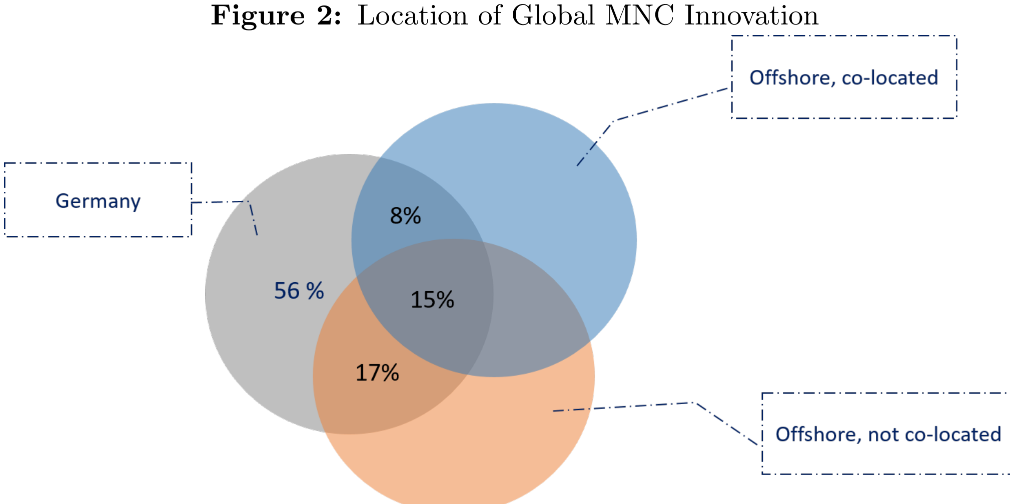
[14] A subset of patents report multiple inventors. We consider a patent foreign invented as long as at least one of its inventors is based abroad. Among foreign-invented multi-inventor patents, approximately half have all inventors

level, 14% of all patents and 16% of all EP patents in our sample are considered offshore, having at least one inventor abroad.

Fact 2: *MNCs innovate in multiple locations, and offshore innovation to locations both with and without affiliates.*

We next document the extent to which German multinational firms offshore research activities to foreign countries. The Venn diagram in Figure 2 summarizes the global organization of MNC innovation at the firm level over the period of interest. 56% of all innovating multinationals file only patents that have been developed at home. Some 8% conduct patent-generating innovation both at home and in another country where they maintain a production affiliate, while 17% do so both at home and in a third country with no subsidiary. Fully 15% of firms undertake patented research in all three location types. For consistency, these figures describe the baseline sample of EP patents, but very 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 patent activity in 1999-2016. Each segment indicates the share of firms that file EP patents with inventors residing at home in Germany, offshore in a country with an MNC affiliate, and/or offshore in a country with no MNC affiliate. N = 2,030 MNCs.
Data sources: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Table 2 provides a complementary summary of the global geography of innovation at the level of the individual patent. 83% of all EP patents filed by German MNCs result from innovation activity within Germany. Of the patents generated abroad, 72% are invented in countries where the MNC runs a production affiliate, with the remaining 28% not co-located with production. Distinguishing between science-based and non-science-based patents reveals that basic research is disproportionately more likely to be offshored and to be offshored to locations without a production affiliate: 23% of

located abroad, and half have a mixed team of inventors in Germany and abroad. Among the latter, about a third of the inventor team is based abroad on average.

all basic patents are generated abroad, of which 69% in countries with a subsidiary. In comparison, only 15% of applied patents originate abroad, of which 75% in countries with a subsidiary.

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 presents the distribution of inventor locations across all EP patents of German MNCs in 1999-2016. Patents are classified into basic (science-based) and applied (non-science-based) based on backward citations to scientific journal articles. Patents can be invented at home, offshore in a country with an MNC affiliate, and offshore in a country with no MNC affiliate.
Data sources: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Fact 3: *Larger MNCs innovate at higher intensity and quality.*

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 potential concerns with citation truncation. Appendix Figures C-2A and C-2B replicate the stark positive relationships in these graphs for the full sample of PATSTAT patents. For completeness, Appendix Figures C-3 and C-4 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.

3 Theoretical Framework

Motivated by the empirical facts established in Section 2.2, we develop a theoretical model of multinational activity that characterizes the global organization of firms' production and innovation. We adopt a stylized, partial-equilibrium setting in order to transparently illustrate the key economic mechanisms that govern firm decisions, while retaining analytical tractability.

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 which they sell at home and potentially also abroad. Consumers exhibit love of variety, such that the representative consumer in

Figure 3A: MNC Size and Innovation Intensity

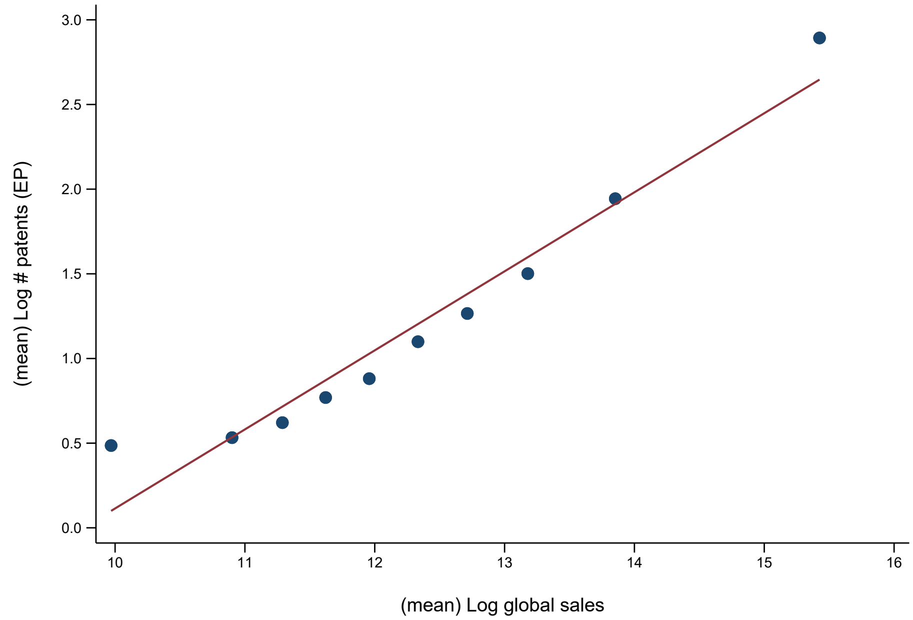
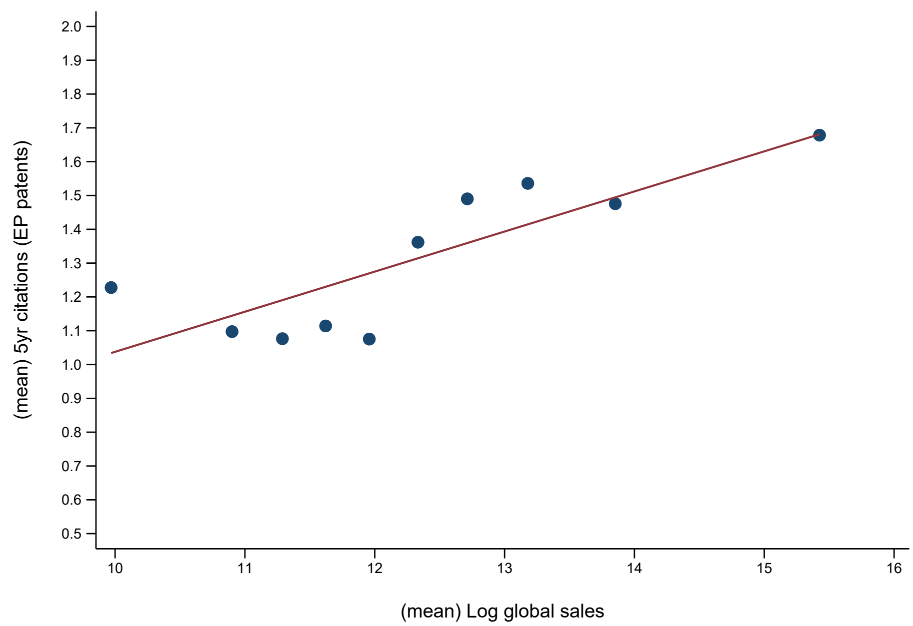


Figure 3B: MNC Size and Innovation Quality



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: Research Data and Service Center of the Deutsche Bundesbank, MiDi, 1999-2016, combined with PATSTAT, own calculations.

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 x_{ji} is the quantity consumed of variety i, and Ω_j is the set of goods available to j. The elasticity of substitution across products is $\sigma \equiv 1/(1-\alpha) > 1$, with $0 < \alpha < 1$. If total expenditure in country j is R_j, j's demand for variety i is $x_{ji} = R_j P_j^{\sigma-1} p_{ji}^{-\sigma}$, where $P_j = \left[\int_{i\in\Omega_j} (p_{ji})^{1-\sigma} \, di\right]^{\frac{1}{1-\sigma}}$ is the ideal price index, and p_{ji} is the price of good i in market j.

In each country, two types of labor engage respectively in manufacturing consumption goods and in innovation. Firms take the wages of production and innovation workers, w_j and r_j, as exogenously determined in the labor market. This assumption can be microfounded, for example, with the presence of two freely tradeable homogeneous goods, each produced by a different type of labor under constant returns to scale and fixed aggregate labor endowments.

We are interested in understanding the production and innovation decisions of multinational companies. We therefore examine the operations of firms headquartered in West, and interpret the exogenous variation in w_j and r_j as cross-country differences in comparative advantage in production vs. innovation. To focus on meaningful trade-offs in Western firms' profit maximization, we assume that $w_S < w_W$, $w_S < w_E$, $r_W \leqslant r_S$, and $r_E \leqslant r_S$. This ensures that South has absolute and comparative advantage in production compared to both East and West, while East and West have comparative (and potentially absolute) advantage in innovation compared to South.[15]

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. Each innovation activity can be performed by headquarters at home, in-house by a foreign production affiliate, and/or at arm's length by a foreign unaffiliated party. Firms can choose

[15] While wages in advanced economies might in practice be higher than in emerging markets for both production and innovation workers, the assumed wage pattern can be seen as accounting for cross-country differences in the quality of innovators and of complementary inputs to innovation outside the model.

to 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.

These two types of innovation can be illustrated with an intuitive example: if a pharmaceutical company discovers a new chemical reaction today (basic innovation), this could improve its future chances of developing a more effective drug formulation or a more efficient production process (applied innovation).[16]

Innovation costs increase with innovation quality, and depend on the location and organization of innovation activity. The cost of innovation of quality q in country j is $\mathbf{1}(q_j^{RD} > 0) r_j \left(f_{j,ORG}^{RD} + \frac{\left(q_j^{RD}\right)^\beta}{\beta} \right)$, where r_j is the inventor wage in j, $RD = \{B, A\}$ indicates the type of innovation ($B =$ basic, $A =$ applied), $ORG = \{I, O\}$ denotes whether innovation occurs within firm boundaries ($I =$ in-house, $O =$ outsource), and $\beta > 1$.[17]

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 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 otherwise independent of the Western firm's organizational structure, $f_{W,I}^B = f_{W,O}^B < f_{E,I}^B = f_{E,O}^B = f_{S,I}^B = f_{S,O}^B$. This captures the idea that communication, monitoring and incentive provision require more financial and managerial resources when headquarterts 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 offshored, but lower fixed costs in any location when it is performed in-house and therefore co-located with production, $f_{W,I}^A < f_{E,I}^A = f_{S,I}^A < f_{W,O}^A < f_{E,O}^A = f_{S,O}^A$. This reflects the scope for synergies

[16] In a richer framework, we have considered multi-product firms that draw firm-wide productivity and firm-product specific expertise. Multi-product firms can then pursue applied process innovation to lower marginal production costs across all products and applied product innovation to lower product-specific fixed production costs. Our main theoretical results continue to hold, with more productive firms innovating more intensively and more frequently abroad across all innovation types.

[17] For tractability, we consider a static model that is qualitatively isomorphic to a dynamic model in which sunk innovation costs are captured by constant per-period amortized fixed costs.

between owner-operated 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 design and implementation 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 attached to a production unit, be it owner-operated or independent. By contrast, the R&D team at an owner-operated 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.

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. Optimal decisions are uniquely determined by productivity as the single dimension of firm heterogeneity. However, the model can in principle accommodate various patterns of MNC activity in different segments of the parameter space that govern countries' absolute and comparative advantage in production and innovation. Motivated by the stylized facts above, we make two simplifying assumptions in order to focus on the empirically relevant case and the novel mechanisms of interest. These assumptions yield considerable transparency and tractability with little loss of generality.

First, we abstract away from trade costs, such that all consumers have access to all varieties produced in the world. This implies that firms face the same global demand regardless of where they manufacture, captured by world aggregate expenditure R and a worldwide 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 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. Given this organizational structure, the relevant country-specific fixed innovation costs for a multinational headquartered in West become $f^B_{W,O} < f^B_{E,O} = f^B_{S,I}$ for basic R&D and $f^A_{S,I} < f^A_{W,O} < f^A_{E,O}$ for applied R&D.

In this environment, a Western firm may choose to remain domestic and produce in-house at home. Such a firm may decide to innovate only in-house at home in W, only at arm's length abroad (in S and/or in E), or both. Alternatively, a Western firm may choose to become multinational and offshore production to an affiliate in S. This multinational may furthermore innovate only at home in W, only abroad (in-house at S and/or at arm's length in E), or both. In other words, firms' innovation strategy can span multiple locations and mix in-house and arm's length R&D. Of note, interdependencies between production and innovation can in principle make it profitable to offshore both, even if offshoring each activity alone might not be desirable.

Upon entry, a Western firm will 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 option is more profitable. With fixed FDI costs, firms above a certain productivity threshold will endogenously sort into multinational activity, consistent with the prior theoretical and empirical literature.

Given our interest in global MNC operations, we henceforth consider the profit maximization problem of a multinational company headquartered in West with a production affiliate in South and no subsidiary in East:

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

The MNC global strategy is characterized by the location of production (here, South), the output quantity x and price p, and the incidence and quality q_j^{RD} of each innovation activity RD in each location j. We denote this strategy as $\mathbf{G}\equiv\left\{p,x,\left\{q_j^B,q_j^A\right\}\right\}$. Note that innovation costs are additively separable across locations and innovation types. In contrast, innovation returns are not, because applied innovation additively reduces marginal production costs, while basic innovation multiplicatively increases variable profits $\widetilde{\pi}(\varphi)$.

3.4.1 Optimal Production Conditional on Innovation Strategy

The MNC problem (1) can be reduced to first determining the optimal production level and pricing 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. Under monopolistic competition and CES consumption preferences, firms therefore optimally charge a constant mark-up $1/\alpha$ above marginal cost, and generate the following output quantity and sales revenues:

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

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

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

Note that greater 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 both types of innovation. Note also that conditional on an innovation strategy, more productive firms as usual 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

The global production and innovation strategy that maximizes MNC profits can be determined by incorporating the optimal production strategy conditional on innovation activity from equations (2a) and (2b) into equation (1) and solving for the optimal innovation strategy in the reduced firm problem:

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

The firm faces a complex choice set with respect to the global organization of its innovation activity. It can in principle choose to conduct each of basic and applied R&D in any subset of the three possible country locations and at varying intensity levels. The global innovation strategy can thus be characterized by a vector of 6 non-negative innovation quality levels, $\left\{q_W^B,q_E^B,q_S^B,q_W^A,q_E^A,q_S^A\right\}$, which are jointly determined by the following set of first-order conditions:

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

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

$$R\left(P\alpha/w_S\right)^{\sigma-1}\left(1+\sum_j q_j^B(\varphi)\right)\left(1+\sum_j q_j^A(\varphi)\right)^{\sigma-2}\varphi^{\sigma-1}\left(\sigma-1\right)/\sigma = r_j\left(q_j^A(\varphi)\right)^{\beta-1},\ q_j^A(\varphi) \geqslant 0. \tag{4b}$$

Although there is no closed-form solution to equations (4a)-(4b), the optimal innovation strategy exhibits 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 with 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 whenever applied innovation lowers marginal production costs. 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. This occurs because expected profits increase linearly with firm-level global basic innovation. However, optimal local basic innovation 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. As a result, there is complementarity in basic innovation intensity 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 production profits, they incur additively separable costs across locations and innovation types, i.e. $\partial^2 F\left(\varphi\right)/\partial q_j^A \partial q_{j\prime}^A =$

$\partial^2 F(\varphi)/\partial q_j^B \partial q_{j'}^B = \partial^2 F(\varphi)/\partial q_j^A \partial q_{j'}^B = 0$. 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 global production and innovation activity delivers rich predictions for the pattern of MNC operations. We focus here on the novel results for the optimal innovation strategy of multinational firms. These stem from the combination of firm heterogeneity in productivity and the rich structure of innovation costs and returns that depend on its location, integration and quality.

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 be incetivized to innovate more actively for two reasons. Along the intensive margin, firm profits are supermodular in productivity and innovation quality of either basic or applied type, $\partial^2 \pi(\varphi)/\partial\varphi\partial q_j^B > 0$ and $\partial^2 \pi(\varphi)/\partial\varphi\partial q_j^A > 0$. Intuitively, applied innovation directly 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 are true for each type of innovation activity, basic and applied. They hold for any given location and, aggregating across locations, 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 offshore innovation and to innovate in more countries.*

Proof. See Appendix A. □

More productive firms will be more likely to innovate abroad 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 ($f^B_{W,O} < f^B_{E,O} = f^B_{S,I}$ for basic R&D and $f^A_{S,I} < f^A_{W,O} < f^A_{E,O}$ for applied R&D due to co-location advantage), this productivity threshold will tend to be higher for offshore innovation (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 offshore innovation to 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 at least one of the two types of R&D.

Recall that we consider the innovation strategy of multinationals headquartered in West that operate a subsidiary in South. If such a multinational opts to innovate in both East and South, it would be conducting both 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 both in locations with and in locations without a production affiliate.*

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

Proposition 3. *An MNC is more likely to innovate and to innovate more intensively in countries with lower inventor wages.*

Proof. See Appendix A. □

When deciding where to undertake innovation, firms find it advantageous to choose 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 conditions (4a) and (4b). Consider equation (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 their relevant technological area. If inventor wages vary both across countries and sectors, Proposition 3 would imply that innovation activity responds to countries' comparative advantage in innovation across sectors:

Corollary 2 *An MNC is more likely to innovate and to innovate more intensively in a given sector in countries with lower innovator wages in that sector.*

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

Proposition 4. *Applied innovation is more likely to be co-located with production than 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 strictly lower when it is co-located with production. All else constant, this implies that a multinational will be more likely to find it profitable to pursue applied R&D in countries where it also operates a manufacturing affiliate.[18]

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, MNCs have an incentive to perform R&D both at home and abroad, in order to increase current and/or future profits (*Fact 1*). Moreover, the variation in innovation activity across firms can be attributed to more productive MNCs choosing to innovate at greater intensity, which manifests in the data as both more patents and higher average patent quality as measured by patent citations (*Fact 3*).

The model also suggests that MNCs may offshore innovation to benefit from cross-country differences in inventor wages. They can furthermore choose whether or not to co-locate each type of foreign innovation with foreign production depending on the associated innovation costs and returns. The observed distribution of offshoring and co-location of innovation activity across multinationals can thus be attributed to heterogeneous firm productivity, combined with variation across innovation types within firms (*Fact 2*). For example, the least productive MNCs may opt to innovate only at home, while the most productive MNCs may undertake applied innovation in locations with an affiliate (where production wages are low and there are synergies with production) and basic innovation in locations without an affiliate (where inventor wages are low and synergies with production are irrelevant).

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 1-3*.

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:

$$I_{ft} = \alpha + \beta\varphi_{ft} + \delta_s + \delta_t + \varepsilon_{ft}, \tag{5}$$

$$I_{fact} = \alpha + \beta\varphi_{ft} + \gamma_{RCA} RCA_{act} + \delta_a + \delta_c + \delta_t(+\delta_f) + \varepsilon_{fact}, \tag{6}$$

$$I_{fpt} = \alpha + \beta\varphi_{ft} + \gamma_{RD} D_{RD=A} + \delta_a + \delta_t(+\delta_f) + \varepsilon_{fpt}. \tag{7}$$

[18] The cost synergies between applied innovation and production may also manifest in lower variable innovation costs, such that total applied innovation costs are $f^A_{j,ORG} + \mu^A_{j,ORG}\frac{(q_j^{RD})^\beta}{\beta}$, where $f^A_{S,I} < f^A_{W,O} < f^A_{E,O}$ as in the baseline and $\mu^A_{S,I} < \mu^A_{W,O} = \mu^A_{E,O} = 1$. If so, both the incidence and the quality of applied innovation would be higher when co-located with production.

In regression (5), the outcome variable I_{ft} reflects various aspects of multinational firm f's innovation activity in year t, such as an indicator for having any patents, the (log) number of patents, and the (log) average number of citations per patent. 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. For instance, δ_t would capture any changes in Germany in production and innovation wages, tax regime, or trade and investment promotion policies. We further account for observed and unobserved sector characteristics that may govern innovative activity with a full set of 23 sector fixed effects, δ_s, based on the primary industry of activity of each parent company in the 2-digit NACE 2.0 classification. 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 a multinational firm's productivity φ_{ft}. As in standard heterogeneous-firm models of international trade and investment, in our framework too global firm sales are monotonic in firm productivity. The main advantage of using this proxy is that it poses minimal data requirements and is not subject to potential estimation biases in constructing productivity measures from accounting statements. In particular, while rich in many dimensions, the MiDi data on German MNCs is not sufficiently detailed to permit rigorous total factor productivity estimates.

Through the lens of the model, innovation activity and total revenues are joint outcomes of the firm's profit maximization problem. We therefore interpret coefficient β as a conditional correlation consistent with the model's predictions, rather than the causal effect of productivity underlying it. As we demonstrate below, the results are robust to using (log) sales per worker at the MNC headquarters as an alternative indicator of labor productivity.

In regression (6), we unpack firms' patent activity to analyze outcomes I_{fact} that characterize firm f's innovation within technological area a in country c at time t. These include the (log) number of patents and (log) number of citation-weighted patents generated (i.e. log total citations). Given the sparsity of firm patenting, we consider 3 non-overlapping 5-year periods t (2002-2006, 2007-2011, 2012-2016), where the outcome variable aggregates up patenting activity within the period of interest.[19] We map each patent to one of 34 technology areas following Schmoch (2008), in order to assess the heterogeneity in innovation activity across firms and countries within technology classes. In addition to parent firm productivity, φ_{ft}, we now also consider countries' revealed comparative advantage by technology area and year, RCA_{act}, as constructed below. Country fixed effects, δ_c, condition on the overall institutional and economic environment in a given country, to isolate the role of differences in innovation conditions across technology areas within countries. 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 versions of equation (6) add firm fixed effects,

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

to further control for time-invariant firm characteristics that shape patent activity irrespective of technology area or country of invention. We continue to cluster errors ε_{fact} at the firm level.

We construct a novel measure of countries' revealed comparative advantage, RCA_{act}, that conceptually maps to inventor wages in the model. This measure aims to capture countries' capacity to enable patent-generating innovation in different technological classes. We define RCA_{act} as the number of patents generated in technology area a in country c at time t, as a percent share of all patents originating in that country and period. Scaling by the total number of patents ensures that the variation in RCA_{act} across countries is not driven by country size, and implicitly also subsumes cross-country differences in absolute advantage in innovation.

To build an informative RCA_{act} measure, we first identify all patent families in PATSTAT that contain patent applications filed on three continents, i.e. with at least three of the top five leading patent authorities in the world. In particular, we consider patent families that include at least one application each at the European Patent Office (EPO); at the United States Patent and Trademark Office (USPTO); and at the Japan Patent Office (JPO), Korean 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.[20] To avoid circularity, we exclude patent families with German applicants. Given this definition of RCA_{act} and the inclusion of country and technology area fixed effects, specification (6) thus identifies how the innovation strategy of multinational firms responds to a country's comparative advantage in innovation in a given technology area, relative to other countries and technology areas.

Finally, in regression (7), we examine innovation outcome I_{fpt} at the most granular level of individual patents, indexed by the firm-patent-year triplet fpt. In these specifications, I_{fpt} is a binary indicator for offshore innovation being co-located with production. In addition to parent-firm productivity, φ_{ft}, the main right-hand side variable of interest is a dummy for non-science-based patents representing applied R&D, $D_{RD=A}$, with science-based patents (i.e. basic R&D) the excluded category. Year, technology area and firm fixed effects, δ_t, δ_a and δ_f, control for firm idiosyncrasies and exogenous variation in innovation conditions across time and technology areas. We once again cluster errors ε_{fpt} by firm, this time to accommodate correlated shocks to research and development operations 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

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

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.

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 size and innovation intensity for German MNCs in 1999-2016, based on equation (5). Panel A includes all MNCs and all EP patents of innovating MNCs. Panels B and C restrict the sample to all innovating MNCs and their basic and applied EP patents, respectively. Patents are classified into basic (science-based) and applied (non-science-based) based on backward citations to scientific journal articles. The outcome variable 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Panel A of Table 3 establishes that larger MNCs pursue systematically more innovation activities. Column 1 first indicates 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 own 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 sizeable: the estimates imply that doubling firm size 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 have superior innovative performance within each R&D type. In particular, we repeat the regression analysis in Panel A separately for science-based and non-science-based patenting, in the subsample of patenting multinationals. Since not every innovating company owns 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 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 and have information on patent type, 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 size. 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 outsourcing production and innovation might influence employment levels and composition at headquarters.

4.3 Innovation offshoring

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 sizeable fixed costs associated with offshore R&D.

We first analyze whether a firm conducts any offshore innovation by estimating specification (5) in the panel of patent-active MNCs, with an indicator for at least one patent originating abroad as the outcome of interest.[21] 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 the incidence of offshore basic (science-based) and applied (non-science-based) 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 pursuing innovation of either type 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. Instead, they generate a bigger share of their patent portfolio in foreign locations. 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 (science-based) and applied (non-science-based) patents.

Panel C of Table 4 confirms that larger MNCs offshore R&D to more foreign locations, by setting the outcome variable in equation (5) to the number of foreign inventor countries 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 innovation

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

Table 4: Innovation Offshoring

	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 size and offshore innovation activity for innovating German MNCs in 1999-2016, based on equation (5). The dependent variable is an indicator for any foreign-invented patents in Panel A, the share of patents invented abroad in Panel B, and the number of host countries for foreign-invented patents. 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 (science-based) and applied (non-science-based) 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

locations. Even columns explore the extent to which this reflects bigger multinationals operating more production subsidiaries worldwide, by expanding the specification to include the number of host countries in an MNC's affiliate network. Multinationals that produce in more countries are also more likely to innovate in more countries, with a somewhat larger elasticity for non-science-based patents than for science-based 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. In other words, bigger multinationals pursue patent-generating R&D in more countries even controlling for the number of their production locations.

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 to 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 a production base, 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 the implication of Corollary 1 that bigger multinationals are more likely to pursue research and development in locations both with and without a production affiliate. 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 production subsidiary, compared to inventing in either location type alone. Columns 3-4 confirm that this is not driven by bigger MNCs maintaining production 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 and production. 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 Offshoring

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 size and the choice of offshore innovation locations for German MNCs with offshore innovation in 1999-2016, based on a multinomial logit regression. The dependent variable takes the value 1 if the firm has any offshore patents invented in a country without an affiliate, value 2 if it has any offshore patents invented in a country with an affiliate, and value 3 if it has 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

4.4 Innovation comparative advantage

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

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 in a given technology area and offshore innovation activity by German MNCs across countries and technology areas, based on equation (6). Data is aggregated into three non-overlapping five-year periods (2002-2006, 2007-2011, 2012-2016). The outcome variable 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

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

We obtain similar results when we instead use an alternative measure of revealed comparative

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 for applied patents in Panel B. Patents are classified into basic (science-based) and applied (non-science-based) based on backward citations to scientific journal articles.
Data sources: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

advantage in innovation that captures the variation in a country's innovation propensity across technology areas, relative to the cross-area variation for the world as whole.[22] In particular, we scale the share of patents in a technology class among all patents invented in a given country by the corresponding global share of that technology class 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 class 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. We document that conditional on offshoring innovation, firms are systematically more likely to co-locate applied R&D with production 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)	(5)	(6)
Non-science-based patent (0/1)	0.028	0.012^{+}			0.039^{**}	0.013^{*}
	(0.025)	(0.006)			(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	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	Yes	No	Yes	No	Yes
# patents	22,051	21,819	21,997	21,765	21,997	21,765

Notes: This table examines the propensity of German MNCs to co-locate offshore basic and applied patent invention with a production affiliate in 1999-2016, based on equation (7). Patents are classified into basic (science-based) and applied (non-science-based) based on backward citations to scientific journal articles. The outcome variable 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

We analyze co-location strategies at the patent level in Table 7. For each patent, we construct a binary variable equal to 1 if the patent belongs to a parent company with an active production affiliate in the country of invention. We use this indicator as the outcome of interest in estimating

[22] These results are available upon request.

equation (7). Columns 1-2 suggest that applied (non-science based) patents are more likely to be developed alongside production operations than basic (science-based) patents. This relationship is moreover statistically significant in the more stringent specification that exploits the variation across patents and locations within firms by conditioning on firm fixed effects.

Since firm size and R&D type jointly determine MNCs' patent location decisions, we examine their combined role in the remainder of Table 7. Columns 3-4 first confirm that larger multinationals are more likely to develop their new technologies in host countries with an active subsidiary. This result is related to, but goes beyond the predictions of Proposition 2 and Corollary 1 that more productive firms are more likely to innovate in multiple locations, including countries with and without production affiliates. Once we control for this firm size effect in Columns 5-6, we find strong evidence that applied innovation is systematically more likely to be co-located with production than basic innovation, even when looking across patents within firms.

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 uniquely rich data on the network of production affiliates and patents 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 offshore more innovation to more countries, spanning both countries with and without a production affiliate. Finally, MNCs pursue innovation across countries and technology classes following countries' comparative advantage, with applied innovation more likely to be co-located with production than basic innovation.

Our findings open the door to various avenues for future research. Richer information on the inputs and outputs of innovation activities, 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 offshoring 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.

References

Ahmadpoor, M. and Jones, B. F. (2017). The dual frontier: Patented inventions and prior scientific advance. *Science*, 357(6351).

Arkolakis, C., Ramondo, N., Rodríguez-Clare, A., and Yeaple, S. (2018). Innovation and production in the global economy. *American Economic Review*, 108(8):2128–2173.

Bernard, A. B., Fort, T. C., Smeets, V., and Warzynski, F. (2024). Heterogeneous globalization: Offshoring and reorganization. Working paper.

Bilir, L. K. (2014). Patent Laws, Product Life-Cycle Lengths, and Multinational Activity. *American Economic Review*, 104(7):1979–2013.

Bilir, L. K. and Morales, E. (2020). Innovation in the Global Firm. *Journal of Political Economy*, 128(4):1566–1625.

Bircan, C., Javorcik, B., and Pauly, S. (2021). Creation and Diffusion of Knowledge in the Multinational Firm. EBRD.

Branstetter, L. G., Chen, J.-R., Glennon, B., and Zolas, N. (2021). Does Offshoring Production Reduce Innovation: Firm-Level Evidence from Taiwan. NBER Working Paper No. w29117.

Branstetter, L. G., Fisman, R., and Foley, C. F. (2006). Do stronger intellectual property rights increase international technology transfer? empirical evidence from us firm-level panel data. *The Quarterly Journal of Economics*, 121(1):321–349.

Danzer, A., Feuerbaum, C., and Gaessler, F. (2020). Labor supply and automation innovation. Max Planck Institute for Innovation & Competition Research Paper 20-09.

de Rassenfosse, G., Dernis, H., Guellec, D., Picci, L., and De La Potterie, B. V. P. (2013). The worldwide count of priority patents: A new indicator of inventive activity. *Research Policy*, 42(3):720–737.

Dechezleprêtre, A., Ménière, Y., and Mohnen, M. (2017). International patent families: from application strategies to statistical indicators. *Scientometrics*, 111:793–828.

Drees, D., Schild, C.-J., and Walter, F. (2018). Microdatabase Direct Investment 1999-2016. Data Report 2018-06 - Metadata Version 5. Deutsche Bundesbank Research Data and Service Centre.

Fan, J. (2021). Talent, Geography, and Offshore R&D. Working paper.

Farre-Mensa, J., Hegde, D., and Ljungqvist, A. (2020). What is a patent worth? Evidence from the US patent “lottery”. *The Journal of Finance*, 75(2):639–682.

Fort, T. C., Keller, W., Schott, P. K., Yeaple, S., and Zolas, N. (2020). Colocation of Production and Innovation: Evidence from the United States. Working paper, Dartmouth College.

Galasso, A. and Schankerman, M. (2018). Patent rights, innovation, and firm exit. *The RAND Journal of Economics*, 49(1):64–86.

Gong, K., Li, Y. A., Manova, K. B., and Sun, S. T. (2023). Tickets to the Global Market: First US Patent Awards and Chinese Firm Exports. HKUST Business School Research Paper No. 2023-120.

Hall, B. H., Jaffe, A., and Trajtenberg, M. (2005). Market value and patent citations. *RAND Journal of economics*, pages 16–38.

Harhoff, D., Narin, F., Scherer, F. M., and Vopel, K. (1999). Citation frequency and the value of patented inventions. *The Review of Economics and Statistics*, 81(3):511–515.

Harhoff, D., Scherer, F. M., and Vopel, K. (2003). Citations, family size, opposition and the value of patent rights. *Research policy*, 32(8):1343–1363.

Helpman, E., Melitz, M. J., and Yeaple, S. R. (2004). Export Versus FDI with Heterogeneous Firms. *American Economic Review*, 94(1):300–316.

Javorcik, B. S. (2004). The composition of foreign direct investment and protection of intellectual property rights: Evidence from transition economies. *European economic review*, 48(1):39–62.

Kline, P., Petkova, N., Williams, H., and Zidar, O. (2019). Who Profits from Patents? Rent-Sharing at Innovative Firms. *The Quarterly Journal of Economics*, 134(3):1343–1404.

Krieger, J. L., Schnitzer, M., and Watzinger, M. (2023). Standing on the Shoulders of Science. Harvard Business School Working Paper 21-128.

Liu, J. (2023). Multinational Production and Innovation in Tandem. Working paper. New York University.

Marx, M. and Fuegi, A. (2020). Reliance on science: Worldwide front-page patent citations to scientific articles. *Strategic Management Journal*, 41(9):1572–1594.

Michel, J. and Bettels, B. (2001). Patent citation analysis: A closer look at the basic input data from patent search reports. *Scientometrics*, 51:185–201.

Ramondo, N., Rappoport, V., and Ruhl, K. J. (2016). Intrafirm trade and vertical fragmentation in us multinational corporations. *Journal of International Economics*, 98:51–59.

Sampat, B. and Williams, H. L. (2019). How Do Patents Affect Follow-On Innovation? Evidence from the Human Genome. *American Economic Review*, 109(1):203–36.

Schild, C.-J., Schulz, S., and Wieser, F. (2017). Linking Deutsche Bundesbank Company Data using Machine-Learning-Based Classification. *Technical Report 2017-01. Deutsche Bundesbank Research Data and Service Centre.*

Schmoch, U. (2008). Concept of a technology classification for country comparisons. Final Report to the World Intellectual Property Organisation, WIPO.

Tintelnot, F. (2017). Global production with export platforms. *The Quarterly Journal of Economics*, 132(1):157–209.

Williams, H. L. (2013). Intellectual Property Rights and Innovation: Evidence from the Human Genome. *Journal of Political Economy*, 121(1):1–27.

Yeaple, S. R. (2003). The role of skill endowments in the structure of us outward foreign direct investment. *Review of Economics and statistics*, 85(3):726–734.

Yeaple, S. R. (2013). The Multinational Firm. *Annual Review of Economics*, 5(1):193–217.

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.[23] 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

[23] 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 [24]) 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

[24] 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.

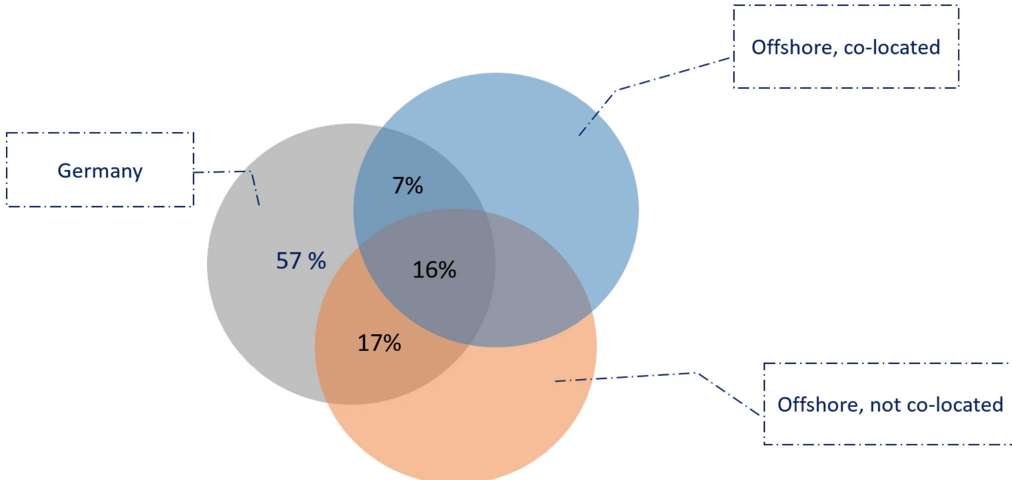
countries using fractional counts as explained above.

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 descriptive findings

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



Notes: This Venn diagram summarizes the global organization of German MNC patent activity in 1999-2016. Each segment indicates the share of firms that file patents with inventors residing at home in Germany, offshore in a country with an MNC affiliate, and/or offshore in a country with no MNC affiliate. N = 2,374 MNCs.
Data sources: Research Data and Service Center of the Deutsche Bundesbank (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. Countries are ranked by their share of all offshore MNC patents. Fractional counts are used for patents with multiple inventor countries.
Data sources: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Figure C-2A: MNC Size and Innovation Intensity: All Patents

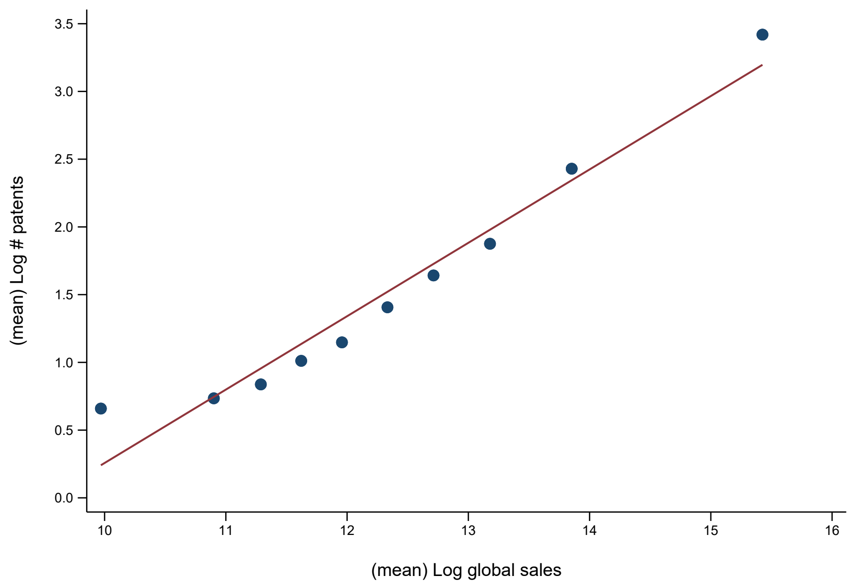
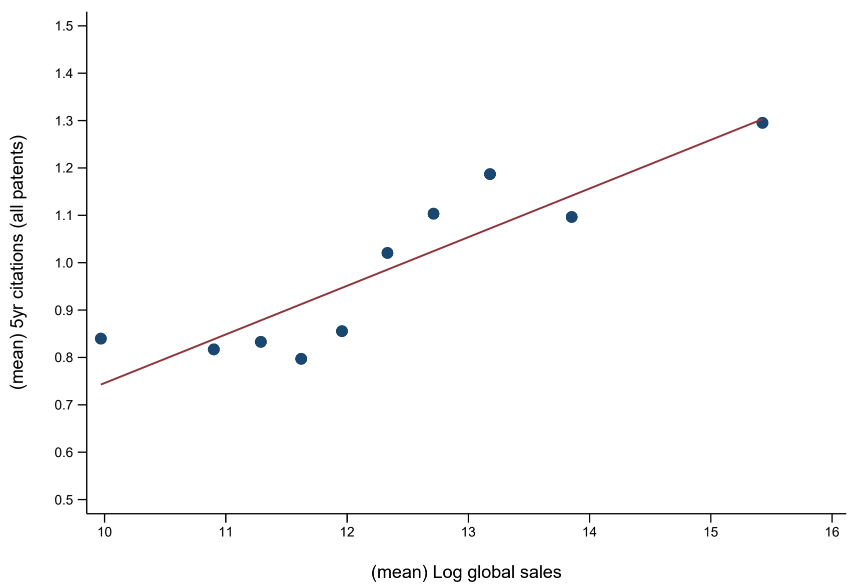
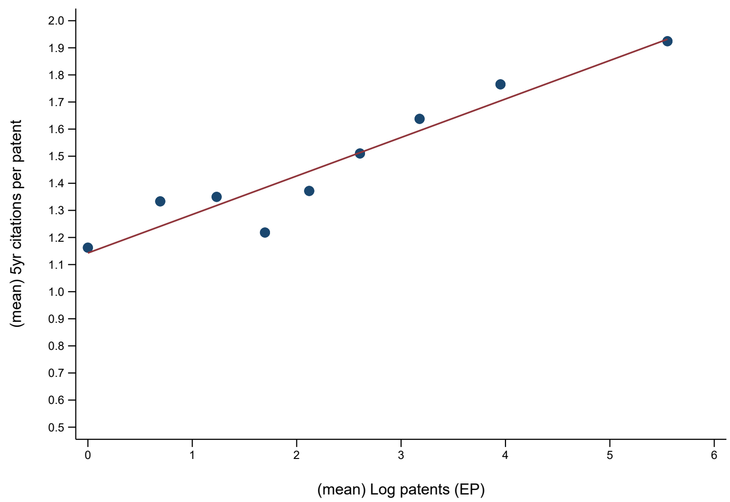


Figure C-2B: MNC Size and Innovation Quality: All Patents



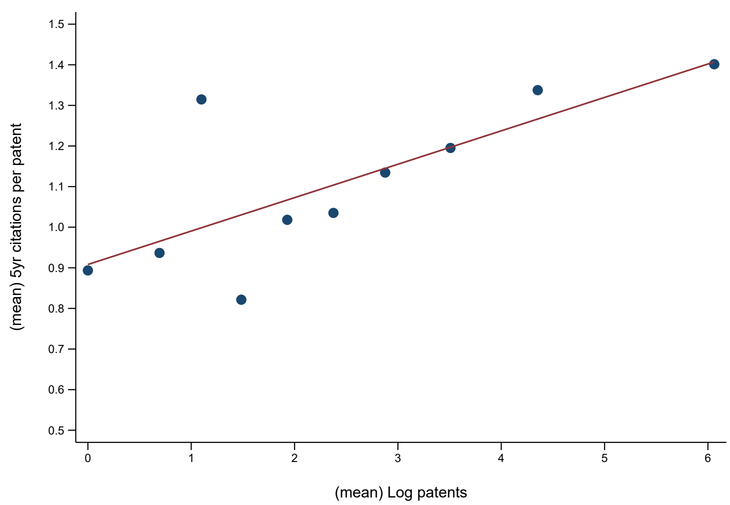
Notes: These binscatters plot the log average annual number of all patents per firm in 1999-2016 and the average number of 5-year forward citations per patent per firm in 1999-2011, by firm size bin. German MNCs are assigned to ten bins each year according to their annual global sales. Year fixed effects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

Figure C-3: 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Figure C-4: 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: Research Data and Service Center of the Deutsche Bundesbank (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 size and innovation intensity for German MNCs in 1999-2016, based on equation (5). The sample includes all MNCs and all patents of innovating MNCs. The outcome variable 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: Research Data and Service Center of the Deutsche Bundesbank (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 A and B include all MNCs and all patents or all EP patents of innovating MNCs, respectively. Panels C and D restrict the sample to all innovating MNCs and their basic and applied EP patents, respectively. Patents are classified into basic (science-based) and applied (non-science-based) based on backward citations to scientific journal articles. The outcome variable 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Table D-3: Innovation Offshoring: 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 innovating German MNCs in 1999-2016, based on equation (5). The dependent variable is an indicator for any foreign-invented patents in Panel A, the share of patents invented abroad in Panel B, and the number of host countries for foreign-invented patents. 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 (science-based) and applied (non-science-based) 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.

Table D-4: Mixed Innovation Offshoring: 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 innovation in 1999-2016, based on a multinomial logit regression. The dependent variable takes the value 1 if the firm has any offshore patents invented in a country without an affiliate, value 2 if it has any offshore patents invented in a country with an affiliate, and value 3 if it has 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: Research Data and Service Center of the Deutsche Bundesbank (MiDi) and PATSTAT, authors' calculations.