Talent, Geography, and Offshore R&D*

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Abstract

I model and quantify the impact of a new dimension of globalization: offshore R&D. In the model, firms employ researchers across the globe to develop new product blueprints and then engage in offshore production and exporting. Frictions impeding trade and the separation of production from R&D lead to a 'market-access' motive for offshore R&D, while cross-country differences in the distributions of firm knowhow and worker ability generate a 'talent-acquisition' motive. I discipline the model using empirical facts derived from a new firm-level dataset. Counterfactual experiments show that the two motives can account for a significant portion of the observed offshore R&D. Incorporating offshore R&D amplifies the gains from globalization by a factor of 1.3 and generates new implications for the impacts of traditional forms of global integration, namely trade and multinational production.

Keywords: Multinational firms, offshore R&D, global value chain, gains from openness

JEL Classification: F21 F23 F40 O32

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1 Introduction

Consider the process of creating and commercializing a new product. Engineers develop prototypes. Firms, with their knowhow—insights into consumer preference, experience with manufacturing production, and brand recognition—oversee prototype development and carry out marketing and production. Both the talent of engineers and the knowhow of firms are vital for this process, but globally, these two factors are distributed unevenly. While emerging economies such as China, India, and Eastern Europe have some of the biggest pools of talented engineers (National Science Board, 2018), the vast majority of the world's best-run firms and most-recognized brands are from a handful of early industrialized countries.[1]

Firms can go abroad—through offshore R&D—to overcome this spatial mismatch. As firms engaging in multinational activities are the biggest ones accounting for the lion's share of global commerce,[2] the R&D they conduct in offshore locations is substantial. In 2012, foreign multinational firms account for more than half of business R&D expenditures in many countries.[3]

By enabling collaboration between firms and talent in different countries, offshore R&D shapes the location and efficiency of global innovation. This paper empirically and quantitatively studies firms' offshore R&D decisions and their aggregate implications. It addresses three questions: What factors determine the direction and scale of offshore R&D. How does offshore R&D interact with trade and multinational production? And how does it affect the gains from globalization?

The first contribution of this paper is empirical. I construct a dataset of firm-level R&D and production, with which I document facts on the joint production and R&D decisions of multinational corporations (MNCs). My dataset builds on two sources. Information on firms' production and the ownership network connecting affiliates to their parents is from Orbis (Alviarez, 2019; Kalemli-Ozcan, Sorensen, Villegas-Sanchez, Volosovych and Yesiltas, 2019). Systematic R&D information for world-wide MNCs is not readily available. I build a new firm-level R&D measure from PATSTAT Global, a database of administrative patent records from over 90 patent offices. I identify where a patent is invented based on the address of inventors, and aggregate across patents to obtain a measure of invention by MNCs at each host. Further refined using information on patent families and firm ownership networks, my measure is robust to where an MNC patents an invention (e.g., the USPTO, the EPO, or both) and which of its affiliates is listed as the patent owner. It is strongly correlated with bilateral offshore R&D measured using R&D expenditures but has the advantage of being widely available as a firm-level panel for many countries.

I document three facts. First, the R&D intensity of an affiliate, measured as the ratio between patent invention and sales, is higher in host countries with better human capital and increases as

[1] Ninety out of the world's hundred most valuable brands are from the G7 countries (Swant, 2019), a group that accounts for only a third of world GDP. Survey evidence shows well-managed firms are also concentrated in a few developed countries (Bloom et al., 2012b).

[2] Multinational firms account for about a third of global production and half of global export (OECD, 2018). Their role in R&D is even more prominent. In the U.S., for example, about 90% of business R&D are carried out by either the affiliate of foreign multinationals or headquarters of U.S. multinationals (National Science Board, 2018).

[3] The number is based on data from the OECD. In the median country covered by the dataset, one-third of domestic R&D is carried out by foreign firms in 2012. This share is higher than the 26% median share of production at foreign firms in these countries. See the Supplementary Appendix for details.

host human capital improves over time. This is consistent with firms conducting offshore R&D in part to tap into the host talent pool—a 'talent-acquisition' motive. Second, R&D and affiliate sales within a firm tend to colocate. Such colocation hints at frictions impeding the separation of R&D from production, which incentivize firms to conduct R&D in hosts where goods can be produced and shipped to customers cheaply—a 'market-access' motive. Third, R&D and sales of overseas affiliates both decrease in distance to the headquarters. This highlights another role of geography: limiting firms' reach to overseas talent and markets. Together, these facts show that talent and geography are crucial factors for offshore R&D that should be incorporated into any quantitative model of multinational R&D and production.

The second contribution of this paper is to build the first model with these factors to interpret the empirical patterns and to quantify their ramifications for offshore R&D and welfare. In the model, firms vary in knowhow, which affects their R&D and production efficiency. Workers differ in talent and choose to be researchers or manufacturing workers. Firms can enter foreign countries to perform R&D, a process that converts local researcher inputs into new differentiated varieties. This offshore R&D decision is then embedded into a tractable general equilibrium model of multinational production (MP) and trade (Arkolakis, Ramondo, Rodríguez-Clare and Yeaple, 2018; ARRY hereafter). Once a product is developed, whether onshore or offshore, the firm selects which countries to sell it to and where to produce it. For example, an American company can develop a new product in Germany, produce it in China, and then export to India.

Host talent endowment and geography play crucial roles in shaping offshore R&D decisions. The importance of talent is intuitive: all else equal, hosts with relatively more talent are more desirable for offshore R&D. The role of geography is more subtle. At the firm level, a host's access to foreign consumers through trade and to manufacturing powerhouses through MP make it more attractive for offshore R&D. However, in the aggregate, the ability to export cheaply leads to more production, which can displace inward offshore R&D. I show that, despite such general equilibrium interactions, the gains from openness can be summarized by a few sufficient statistics. This characterization generalizes the results from ARRY and Ramondo and Rodríguez-Clare (2013) and demonstrates that offshore R&D amplifies the inferred gains from openness.

To quantitatively answer the questions posed earlier, I calibrate the model using micro- and macro data from 36 countries. Three sets of parameters are essential for my quantification. The first is the structural elasticities that govern the shares of production, markups, and R&D spending in sales. The second is the geographic frictions impeding firms' global reach. I calibrate the first using the revenue shares of these items from firm-level data; I disentangle various forms of geographic frictions using indirect inference. Specifically, I specify the cost of offshore R&D as a function of distance between the host country and the headquarters. I specify the cost of production in a host as a function of both that host's proximity to the headquarters and its proximity to where the product is developed. I pin down the parameters in these specifications by matching countries' inward offshore R&D and production shares and the coefficients from firm-level regressions that capture how different geographic frictions impact affiliate R&D and production.

Together, the first two sets of parameters determine how, holding aggregate prices and quantities constant, an increase in R&D spending in one of a firm's locations affects the firm's *global* production and operation profit. The third set of parameters are countries' endowment of knowhow and talent, which govern how the aggregate prices and quantities are shaped by firm- and worker-level decisions. I parameterize each country's distribution of firm knowhow using the World Management Survey built by Bloom et al. (2012b) and its talent distribution using a cognitive test score database developed by Hanushek and Woessmann (2012b). The calibrated model matches the data in both targeted and untargeted moments.

I obtain three main results from counterfactuals. First, both endowment distributions and geography are quantitatively important for offshore R&D. For example, increasing the average talent of Brazil (worst in my sample) to the world average increases the foreign share of R&D in Brazil by half; decreasing the average firm knowhow of the U.S. (best in my sample) to the world average increases the foreign share of R&D in the U.S. by two thirds. If we eliminate the differences in endowments by changing countries' average knowhow to that of the U.S. and average talent to that of Brazil simultaneously, the share of global R&D in offshore locations decrease from 30% to 1%. Market access plays heterogeneous roles: having an access to foreign producers through MP tend to increase inward offshore R&D to a host, whereas having access to foreign consumers through export decreases it. The net effect of having both on offshore R&D turns out large and positive: if both are shut off, countries will see a decline in inward offshore R&D by half on average.

My second result concerns the welfare effects of offshore R&D. The average welfare gains from offshore R&D are around 3.5%. Compared to a restricted model with only trade and MP, incorporating offshore R&D amplifies the average gains from openness by a factor of 1.3. This amplification is larger for advanced countries primarily because a higher share of their income is generated through offshore R&D. Thus, the omission of this channel not only underestimates the gains from openness, but also biases the comparison of the gains across countries.

My third result sheds light on how offshore R&D interacts with trade and MP.[4] In the model, trade and MP allow countries to specialize in either innovation or production according to their comparative advantage. By enabling firms to mobile their knowhow, offshore R&D effectively increases R&D capacity everywhere, which strengthens the comparative advantage of countries already specializing in innovation and weakens the comparative advantage of those specializing in production. As a result, it tends to be a complement to trade and MP for developed countries and a substitute for developing countries. Depending on the case, this interaction can increase or decrease the welfare gains from trade and MP by up to a quarter, so even for researchers whose main concern is on the implications of trade and MP, offshore R&D can be relevant.

This paper contributes to a growing literature that quantifies the impacts of multinational firms (e.g., McGrattan and Prescott, 2009; Burstein and Monge-Naranjo, 2009; Garetto, 2013; Tintelnot, 2016; Cravino and Levchenko, 2017). The closest paper within this literature is ARRY, who develop a model of trade and MP to examine countries' specialization in R&D/production and the resulting gains from openness. This paper differs from ARRY in two main aspects. First and

[4]Throughout this paper, I use 'offshore production' interchangeably with 'multinational production' (MP) to refer to the separation of production from R&D.

foremost, I focus on offshore R&D, which I show to be an important form of globalization. Second, similar to ARRY, I incorporate countries' comparative advantage in R&D as one of the key forces for specialization. However, instead of treating comparative advantage as an exogenous parameter, I model it as jointly determined by country endowments and endogenous offshore R&D decisions. This approach enables me to measure endowment distributions externally and quantify their importance in shaping specialization. Moreover, because comparative advantage is affected by offshore R&D, which reacts to trade and MP, my model implies heterogeneous interactions among the three forms of globalization. My analysis of such interactions also relates to Ramondo and Rodríguez-Clare (2013), who study the interaction between trade and offshore production. Finally, the idea that there are large gains to be had by combining talent and know-how from different countries is related to Chaney (2008). My contribution is to model and quantify the impacts of one specific but significant channel through which this can happen.

The focus of this paper on R&D within MNCs is related to Bilir and Morales (2020), who estimate the local and global effects of R&D among different sites of the same multinational firm. In my model, inventions at overseas affiliates can be produced both locally and globally. My estimate suggests significant frictions in doing the latter, implying that affiliate R&D mostly increases the production in the same host. This is consistent with Bilir and Morales (2020)'s finding based on U.S. MNCs that affiliate R&D does not improve performance at the firm's other sites.

Finally, this paper contributes to the literature on the patterns of FDI. Most closely related, Irarrazabal, Moxnes and Opromolla (2013) and Keller and Yeaple (2013) document a gravity relationship for affiliate production; Hall (2011) measures significant cross-border R&D by MNCs using aggregate patent data; Siedschlag, Smith, Turcu and Zhang (2013) estimates R&D location choice for firms from the EU. My contribution to this literature is two folds. Empirically, I document new facts on the *joint decision* of R&D and production across a broad set of countries, complementing existing studies, most of which focus on either production or R&D alone, often using data from one host or one home country. Quantitatively, I use a model to separate the roles of talent and various geographic frictions in the decisions of MNCs. In doing so, I allow the friction in MP to depend on the proximity to both the headquarters and R&D locations. This assumption shares a similar flavor as recent studies on the role of MNCs in shaping consumer preference (Head and Mayer, 2019; Wang, 2021), where export costs depend on not only the distance between the producer and the consumer, but also the distance between the headquarters and the consumer.

2 Data and Facts

2.1 Data Sources and Empirical Sample

I assemble a dataset on the invention and production activities of world-wide firms, linked by an ownership network. This subsection describe the main data sources and preparation procedures; Appendix A provides details on these procedures and the results from several validation exercises.

Financial and ownership data. The financial and ownership data are from the Historic Disk of Orbis, extracted in April 2017 (Bureau van Dijk, 2017). I use the 2016 vintage of shareholder data to identify the parent of each firm, defined as the entity holding more than 50% control over the firm either directly or indirectly. These ownership data span across country borders, so I can link firms to their overseas as well as domestic parents. Firms not linked to a parent are assumed to be independent.[5]

I group firms in a host belonging to the same parent into one and treat it as an affiliate. This step gives me a total of around 185 million parent firm-host country-year observations over 1996-2016. The vast majority of parent firms have only one host—their home country.

My primary measure of firms' operation is sales. As in the MP literature (e.g. Ramondo et al., 2015), I view sales as a proxy for production and will interpret the facts on sales as such. Of course, sales do not always correspond to production, especially for professional service firms.[6] For robustness, I also use value added, which has more limited availability, or focus on manufacturing firms, for which this concern is less relevant. Table A.1 reports statistics on the coverage of the data set.

Patent data. I measure the R&D of MNCs using the address of patent inventors. The primary data source is PATSTAT (European Patent Office, 2018), which covers patents from 90 national and regional patent offices. I match owners of individual patents to my firm-level dataset using a crosswalk from Orbis Intellectual Property Database, which is generated by matching firms' names (current and past), addresses, and industry, to the standardized information on patents and their assignees. I verify the quality of the match through manual inspections and cross-checks, reported in Appendix A.2.

Around 25 million granted patents are matched to 681,241 unique parent firms from the firm database. Only less than a quarter of these patents are from the USPTO (see Appendix Table A.2 for the composition of matched patents). Thus, by using a comprehensive patent database, I expand coverage among firms patenting outside the U.S., which will provide valuable variation when I relate invention to country characteristics.

I aggregate individual patents to obtain patent counts at the level of year, parent firm, and host country, with host countries identified by the location of inventors. In doing so, it is necessary to take a stand on how to classify patents with inventors in different countries. In the baseline analysis, I split the credit for patents evenly among the inventors residing in different countries. For robustness, I will use an alternative measure that counts each of the inventor locations as having invented the entire patent. Patents vary in quality. In addition to raw patent counts, I will use citation-weighted patent counts for robustness analysis.

My patent-based measure has two advantages relative to measures based on R&D expenditures. First, whereas systematic R&D information is rarely available for more than one host or one home country at a time, information on the universe of world patents is publicly accessible.[7]

[5] I use the 2016, the latest vintage available to me, because the coverage of the ownership information expanded over time. One may be concerned that using time-invariant ownership information can lead to measurement errors. I verify that all results are robust if time-varying ownership information is used. These results are available upon request.

[6] For example, firms in NAICS 54 industry (Professional, Scientific, and Technical Services) often accrue revenues by licensing their intellectual property, in which case using revenue to document the relationship between R&D and production could be problematic.

[7] The lack of comparable data across countries is in part due to different regulations. For example, while listed

Second, MNCs operating in multiple tax jurisdictions have an incentive to manipulate intangibles to shift profit (Guvenen et al., 2017). This incentive might affect the accuracy of affiliate-level R&D expenditures; as firms can assign the ownership of patents to any of its affiliates, it might also affect the location of the assignee (the owner of a patent). Since the addresses of inventors appearing on a patent application do not affect taxes, my measure is less susceptible to such manipulations. In particular, it implies less concentration of invention in tax havens than measures based on either R&D expenditures or assignee locations, see Appendix A.2.

There are also two caveats in using patents to measure R&D. First, patenting is a choice that depends on host and firm characteristics, introducing a selection bias. I address this concern in three ways. In the appendix, I show that for firms with R&D expenditures information, patent count (raw or weighted) is a strong predictor of R&D expenditures; I also show that aggregate and bilateral offshore R&D shares calculated using patent data are strongly correlated with those calculated using expenditures. These two exercises verify the usefulness of patents for both firm-level R&D and country-level offshore R&D. To the extent there are lingering concerns about selection, I will account for it in empirical analysis through a rich set of fixed effects and other controls. Second and more specific to my setting, because a patent only grants protection within the country in which it is issued, firms often seek patents in multiple countries for the same invention. To avoid double counting, I identify patents covering the same underlying invention and exclude duplicates.[8] This treatment also means my measure is unaffected by where an MNC files for a patent, further alleviating the concern that firms selectively apply for patents in particular hosts.

Sample country and time. To have a consistent sample as the quantitative section, I restrict to 37 host countries, chosen based on the coverage of aggregate and firm-level data. To reduce measurement errors from discrete patent outcomes and to smooth out yearly fluctuations in country characteristics, I average the data by five-year intervals between 1996 and 2016.

2.2 Descriptive Statistics

I match the financial and patent data. The majority of firms never patented; some firms with patents have no available financial information. In quantification, I will use the full set of firms to tabulate country-level statistics to ensure good representation of the economy; Appendix A.3 provides a summary of that full sample. For empirical analysis, I focus on firms that *both* have some financial information *and* have filed at least one patent during the sample period. These firms represent on average a third of countries' total sales. In the rest of this subsection, I report statistics on this sample.

Table 1 gives an account of the joint sample. Column 1 is the parent firm count. The numbers increase over time, reflecting the broadening coverage of Orbis. Column 2 is the number of affiliates with positive sales, which I interpret as production locations. On average, each firm operates in 1.5 countries. Column 3 is the R&D center count. As a baseline, I define a host as an R&D center

companies in the U.S. are required to report R&D expenditures, such reporting is not mandatory in many European countries; moreover, the definition of R&D expenditures can also differ across countries (Thoma et al., 2010).

[8] I identify patents from different offices covering the same invention (i.e., patents belonging to the same family) using their common priority, established when the first patent of the family is filed.

Table 1: Sample Structure: Firms, Production Facilities, and R&D Centers

	(1)	(2)	(3)	(4)
			R&D center count	
Period	Firm count	# of aff. with sales	Baseline	Liberal
1996-2000	26,635	43,395	32,508	36,818
2001-2005	48,473	76,641	55,484	61,539
2006-2010	75,336	113,401	83,429	91,703
2011-2016	86,335	131,493	93,730	102,886
Total	236,779	364,930	265,151	292,946

Note: Reported are the numbers of distinct firms (Column 1), distinct affiliates with sales (Column 2), and distinct R&D centers (Columns 3 and 4) in the matched R&D-financial sample. Each row is for a five-year interval over 1996-2016.

Table 2: Descriptive Statistics of the Sample

Panel A: Manufacturing and non-manufacturing shares					
	firm count	% of total revenue		% of total patents	
			% offshore		% offshore
Mfg.	43220	39.71	38.16	56.32	15.23
Non-Mfg.	43115	60.29	24.34	43.68	9.86
All	86335	100.00	30.00	100.00	12.89

Panel B: The distribution of firms by the number of affiliates						
	by the number of aff. with sales			by the number of R&D Centers		
	All	Mfg.	Non-Mfg.	All	Mfg.	Non-Mfg.
1	77447	39,027	38,420	82,498	41,203	41,295
2	3361	1,602	1,759	2,373	1,158	1,215
3	1317	567	750	554	273	281
4	770	337	433	270	148	122
5	513	219	294	180	120	60
>=6	2927	1,468	1,459	460	318	142
Total	86335	43220	43115	86335	43220	43115

Note: Panel A reports sample composition by manufacturing and non-manufacturing firms. Panel B reports the number of firms based on their number of R&D centers and affiliates with sales. Values based on the last period (2011-2016).

of a firm if it invents at least one full patent there. Firms have on average 1.12 R&D centers. Column 4 uses a more liberal definition for R&D centers, which only requires a host to have invented a partial patent. Under this definition, the average R&D center count is 1.24.

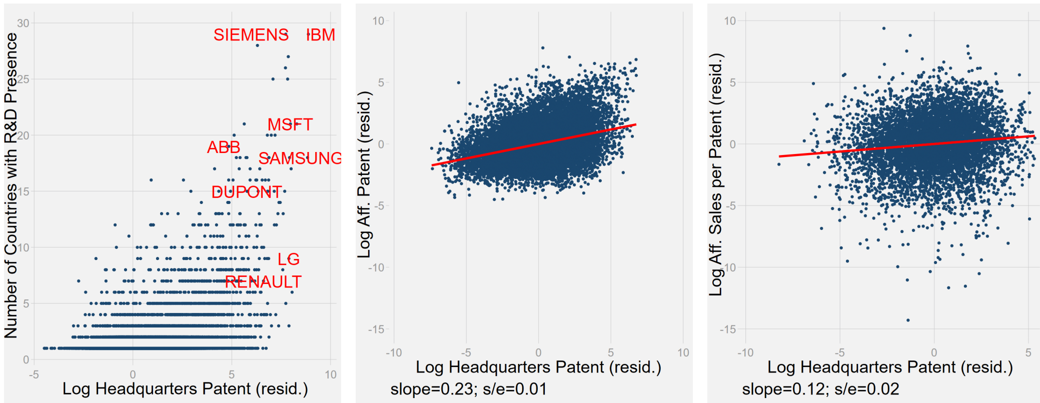
Table 2 provides sample descriptive statistics, focusing on the last period. Panel A reports the composition of the sample by whether a parent firm is in manufacturing. Manufacturing accounts for about half of the firm count, 40% of total revenue, and 56% of total patenting. About 38% of revenue and 15% of patents of these firms are generated in their overseas affiliates. Non-manufacturing firms account for a higher share of revenue but a lower share of patents; their overseas affiliates also carry out non-trivial shares of both sales and invention.

Panel B counts firms by the number of countries they enter. 11% of firms have affiliates with sales in 2 or more hosts, around 3% in 6 or more. In comparison, affiliate R&D is both less common and less spread out: only 5% of firms do so in 2 or more hosts, less than 1% in 6 or more. Interestingly, these patterns do not differ systematically between manufacturing firms and others.

We explore how participation in offshore R&D vary across firms. Figure 1 examines the re-

Figure 1: The Role of Firm Heterogeneity in Offshore R&D

(a) Offshore R&D Presence (b) Affiliate Patent (c) Affiliate Sales per Patent



Notes: Figures use data from the last period only. Panel (a) plots the number of countries a firm enters for offshore R&D against the normalized (by taking out home and 2-digit industry fixed effects) log number of patents at the headquarters. A few technology companies and manufacturing conglomerates are annotated. Panels (b) and (c) are residual plots of log affiliate number of patents and sales per patent, respectively, against the log number of patents at the headquarters, controlling for host country, home country, and 2-digit industry fixed effects. Standard errors reported in Panels (b) and (c) are clustered by firm.

lationship between offshore R&D and firms' innovation efficiency, proxied by the total invention at the headquarters. Panel (a) plots the number of R&D centers of a firm against this proxy, controlling for the systematic differences in patenting intensity across countries and industries using country and industry fixed effects. The figure shows that innovative firms enter more countries for R&D, consistent with self-selection into offshore R&D by knowhow.

Panels (b) plots affiliate-level invention against headquarters invention, controlling for home, host, and industry fixed effects. The strong positive correlation suggests innovative firms tend to have innovative affiliates, in line with recent evidence on knowhow transfer from parents to affiliates (e.g. Keller and Yeaple, 2013; Cravino and Levchenko, 2017).

Panel (c) shows that affiliate sales per patent also increases in parents' invention.[9] This correlation hints at additional sources of heterogeneity that determines an affiliate's sales besides its invention, which my model will incorporate.

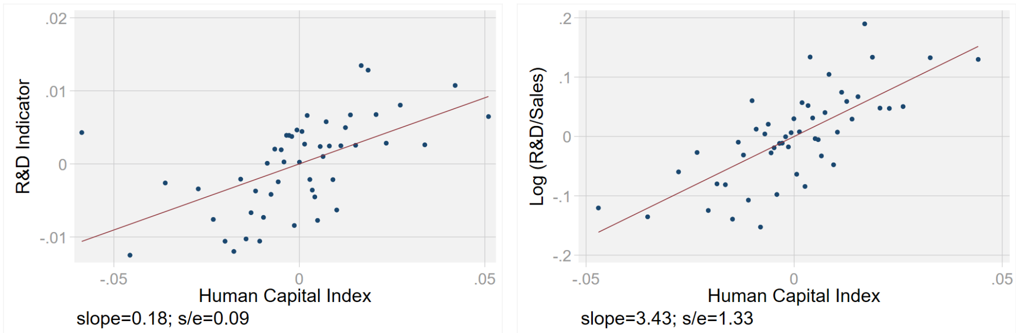
2.3 Three Facts on the Spatial Distribution of R&D and Production

I document three facts on the spatial distribution of R&D and production within an MNC. These facts are presented in figures; underlying/additional regressions are reported in Appendix A.4.

Fact 1: The likelihood and intensity of affiliate R&D increase with host talent quality. Figure 2 depicts the binned scatter plots of affiliate R&D against host talent quality, proxied by the human capital index from the Penn World Table (Feenstra et al., 2016; see Feenstra et al., 2015 for descriptions). Both panels control for firm-period and affiliate fixed effects, and time-varying host characteristics such as their protection of intellectual property and R&D subsidies. To isolate R&D

[9] This pattern echoes a finding by Bilir and Morales (2020) that parents' R&D improves affiliate performance; another important finding of Bilir and Morales (2020) is that affiliate R&D has little impact on sibling affiliates. I discuss reduced-form patterns and the implications of my model pertaining to this finding in Section 3.3 and Appendix C.3.

Figure 2: Host Talent and Offshore R&D



Notes: Figures are binned scatter plots. Both panels control for firm-period and affiliate fixed effects, and time-varying host characteristics such as their protection of intellectual property and R&D subsidies. Standard errors clustered two way, by host and by firm.

decision from the decision of offshore production, I restrict the sample to firm-host pairs in which the firm reports positive affiliate sales.

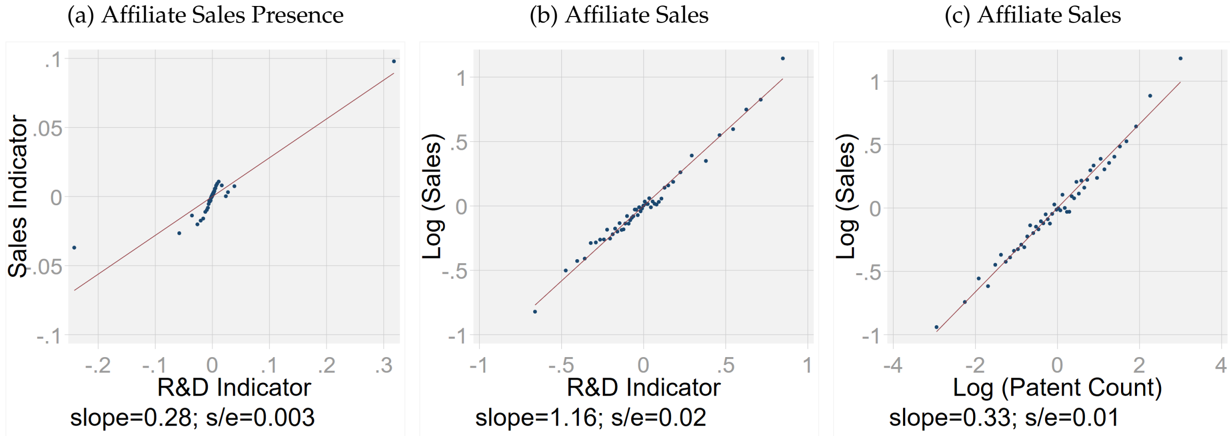
The left panel shows that better talent quality is associated with higher likelihood of affiliate R&D. A one standard deviation improvement in the human capital index (0.38) increases the likelihood by 6.8 p.p., a substantial increase compared to the mean probability (0.37%). The right panel shows that conditional on doing affiliate R&D, the intensity of affiliate R&D, measured using affiliate patent counts over affiliate sales, also increases in host talent quality. A one standard deviation improvement in the human capital index more than doubles affiliate R&D intensity. These patterns highlight the crucial role of host talent quality in a firm's decisions regarding whether to carry out offshore R&D and how much to invest in it.

Fact 2: Co-location between affiliate R&D and sales. Firms' affiliate R&D and sales are spatially clustered. In 2011-2016, conditional on a firm having affiliate sales in a host, the probability that it also has an R&D center there is 15.9% (20.8% under the liberal definition). This is much higher than the unconditional probability of 0.37% (0.67% under the liberal definition).

This clustering is not driven by specific industries, countries, or the few large firms with many affiliates. Figure 3a shows a binned scatter plot of affiliate sales indicator against R&D indicator, controlling for firm-period, home-host, host-period, host-industry fixed effects. It shows that having an R&D center in a host is associated with 28% increase in the probability of having affiliate sales in the same host, about ten times the mean value of the affiliate sales indicator (2.7%). Figures 3b and 3c show, respectively, that the presence and the scale of affiliate R&D centers are strongly correlated with the scale of affiliate sales. The strong colocation is consistent with the effect of offshore R&D on affiliate performance being highly localized, as documented in Bilir and Morales (2020). It also hints at frictions in separating production from R&D. In the presence of trade costs, such frictions imply that R&D may follow production and gravitate towards major destination markets, giving rise to a 'market-access' motive of offshore R&D.

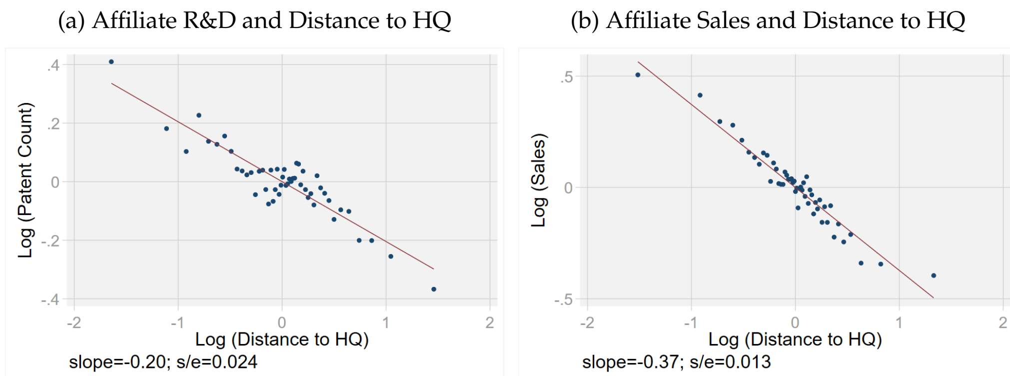
In Appendix A.4, I show that the pattern is robust when we measure proximity to R&D using an average distance to all R&D centers of the firm, thereby enabling co-location effect to take place

Figure 3: Co-location between R&D and Affiliate Sales



Notes: Figures are binned scatter plots of affiliate sales (indicator or log sales) against affiliate R&D (indicator or log patent count); controls include firm-period, home-host, host-period, host-industry fixed effects. Standard errors clustered by firm.

Figure 4: Headquarters Effect on Affiliate R&D and Sales



Notes: Figures are binned scatter plots. Both panels control for firm-year, host-year, and host-industry fixed effects. Standard errors clustered by home-host pairs.

among sibling affiliates. In the Supplementary Appendix, I further show that it is robust when we exploit over-time changes in R&D and sales for identification, and when we use host R&D subsidies and availability of talent as IV for affiliate R&D, which alleviates the concern that the co-location is driven by idiosyncratic match quality between a firm and a host in both R&D and production.

Fact 3: The headquarters effect for affiliate R&D and sales. Figure 4 plots the sales and R&D of affiliates against their distance to headquarters. The scale of both activities clearly decrease with the distance. As shown in Appendix A.4 , similar patterns emerge for extensive-margin measures of sales and R&D. Such patterns lend support to the notion that geographic frictions can impede the transfer of knowhow from parents to affiliates. Thus, even though firms have the incentive to mobilize their knowhow to exploit either the talent or market access of a host, their reach is constrained by the frictions of operating at a distance from the headquarters.

Additional robustness results and summary. In addition to the aforementioned robustness results, I show in the Supplementary Appendix that the facts hold when value added is used as a proxy for production and when only the manufacturing industry is included; they are also robust when we account for the quality of patents by weighting them using forward citations. Together, the reduced-form facts show that host talent and geography (proximity to the headquarters and production) are key factors shaping offshore R&D. I now incorporate these forces in an equilibrium model of global R&D and production by multinational firms.

3 The Model

3.1 Environment

Worker. There are N countries, indexed by $i = 1, 2, ...N$. Country i is endowed with L_i measure of workers, whose ability α is from a cumulative distribution function (cdf) $A_i(\alpha)$. Workers with ability α choose between a low-skill production job, in which everyone is equally productive and earns a common wage of W_i^l, or a high-skill job—R&D and marketing—and earn a wage of $W_i^h \times \alpha$.[10] Letting $\hat{\alpha}_i \equiv \frac{W_i^l}{W_i^h}$ denotes the ability level above which a worker chooses high-skill jobs, the supply of high and low skill efficiency units, denoted by L_i^h and L_i^l, are given by:

$$L_i^h = L_i \cdot \int_{\alpha > \hat{\alpha}_i} \alpha \, dA_i(\alpha); \qquad L_i^l = L_i \cdot A_i(\hat{\alpha}_i).$$

Consumption. Each country has a representative consumer with the following preference:

$$U_i = (\int_{\Omega_i} q_i(\omega)^{\frac{\sigma-1}{\sigma}} d\omega)^{\frac{\sigma}{\sigma-1}},$$

where Ω_i denotes the set of varieties available in country i and $q_i(\omega)$ is the consumption of variety ω. Let the aggregate consumption expenditure in country i be X_i. The demand for variety ω is $q_i(\omega) = p_i(\omega)^{-\sigma} X_i / P_i^{1-\sigma}$, where $p_i(\omega)$ is the price of ω and P_i is the aggregate price index in i.

Firm. Country i is endowed with E_i measure of firms, whose innovation efficiency $\tilde{z}^R$ is distributed according to a cdf $G_i^E(\tilde{z}^R)$ that reflects the knowhow in country i. Firms choose according to $\tilde{z}^R$ whether to open R&D centers in other countries, where they can combine knowhow with local researchers to develop new varieties, and decide where to produce these varieties.

For tractability, I make two assumptions. First, production incurs no fixed cost. As I show below, this leads to closed-form solutions to firms' production decisions. Second, varieties developed by the same firm are differentiated from each other to the same degree as they are differentiated from those developed by other firms. This assumption implies that firms make independent offshore R&D decisions for each host, thereby avoiding an intractable combinatorial problem.[11] I

[10]By modeling occupation choice, I am able to use external data on ability distributions to calibrate $A_i(\alpha)$. An alternative approach is to assume each country has an exogenous endowment of researchers and other types of workers. Parameterizing this alternative model boils down to assuming that the endowment of different types of workers in a country matches the observed occupation shares, which risks attributing variation in other country characteristics that drive occupation choice, such as firm knowhow, to talent endowment.

[11] Although recent works have developed algorithms to exploit *either* complementarity *or* substitution between decisions to tackle such problems (Antras et al., 2017; Arkolakis et al., 2021), in my setting with R&D and production, two decisions can be *both* complementary *and* substitutable, rendering such algorithms inapplicable.

provide further justification for this assumption in the next subsection.

3.2 Offshore R&D Decisions

Consider a firm from country o. It is born with an R&D center in o. Knowing its innovation efficiency, $\tilde{z}^R$, the firm decides how many offshore R&D centers to open and in which countries. Opening an R&D center in country $i \neq o$ requires a pair-specific fixed cost of f_{oi}^R in country i's high-skill efficiency unit. Motivated by Figures 1b and 4a, I assume that depending on the proximity of o and i, firms can transfer part of their knowhow to affiliates. Letting $\phi_{oi}^R \leq 1$ be the fraction of knowhow transferred, the affiliate innovation efficiency is $z^R = \tilde{z}^R \phi_{oi}^R$.

R&D centers recruit high-skill workers to develop new varieties. In quantification, these varieties will be mapped to patents, which has been shown to be a strong predictor of new product introduction (Argente et al., 2018). Letting h be the measure of high-skill efficiency units recruited by an R&D center, the number of new varieties created, v, is:

$$v = z^R \cdot h^\gamma, \; 0 < \gamma < 1. \tag{1}$$

The elasticity γ captures the importance of researchers in product development relative to other affiliate-level fixed factors, embodied in innovation efficiency z^R.[12,13]

Innovative firms tend to have higher manufacturing efficiency/product quality. To allow for this possibility, I assume that each R&D center upon entry obtains a random manufacturing efficiency draw, denoted by $z^P > 0$, which governs the production costs of varieties from that R&D center. The distribution from which z^P is drawn increases in z^R in the sense of first-order stochastic dominance, with its cdf denoted by $G^P(z^P|z^R)$. This assumption implies that on average affiliates of more innovative parents will have not only more sales and more inventions, but also more sales per invention, as documented in Figure 1.

An R&D center in i from o characterized by (z^R, z^P) chooses $h(z^R, z^P)$ to maximize profit. Letting $\overline{\pi}_{oi}(z^P)$ denote the expected per-variety operation profit for this R&D center, its problem is:

$$\pi_{oi}^R(z^P, z^R) = \max_h \overline{\pi}_{oi}(z^P) z^R h^\gamma - W_i^h h,$$

Profit maximization implies researcher input and the number of varieties are, respectively,

$$h_{oi}(z^P, z^R) = \left(\frac{\gamma \overline{\pi}_{oi}(z^P) z^R}{W_i^h}\right)^{\frac{1}{1-\gamma}}, \quad v_{oi}(z^P, z^R) = z^{R\,\frac{1}{1-\gamma}} \left(\frac{\gamma \overline{\pi}_{oi}(z^P)}{W_i^h}\right)^{\frac{\gamma}{1-\gamma}}. \tag{2}$$

[12] Examples of such fixed factors include the capacity of top managers in supervising research or other firm knowhow that do not scale easily. Alternatively, $\gamma < 1$ can also stem from heterogeneous match quality between researchers and the firm, which implies that as firms expand, the average match quality decreases. Decreasing returns in R&D have been invoked in the Schumpeterian growth literature to match the data (see e.g., Acemoglu et al., 2018).

[13] An often invoked rationale for attracting foreign R&D is that it generates spillovers to domestic R&D. By writing v as dependent on z^R but not the knowhow of other firms in the host, my setup overlooks such spillovers. Citations of the patents that are merged to MNCs are well suited for quantifying these spillovers, which is an important venue for future research, but doing so is beyond the scope of this paper.

The total operation profit from these varieties, netted of wage payment to researchers, is

$$\pi^R_{oi}(z^P, z^R) = \left(\gamma^{\frac{\gamma}{1-\gamma}} - \gamma^{\frac{1}{1-\gamma}}\right)\left(W^h_i\right)^{-\frac{\gamma}{1-\gamma}}\left(\overline{\pi}_{oi}(z^P)z^R\right)^{\frac{1}{1-\gamma}}. \tag{3}$$

The expected profit for an R&D center in country i with innovation efficiency z^R is

$$\pi^R_{oi}(z^R) = \int_0^\infty \pi^R_{oi}(z^P, z^R)\, dG^P(z^P|z^R)$$

Firms enter a country for offshore R&D if the expected profit exceeds the fixed setup cost. Under the assumption that $G^P(\cdot\,|z^R)$ increases in z^R, firms from country o will enter country i if and only if its innovation efficiency at the headquarters $\tilde{z}^R$ is above a cutoff $\hat{z}^R_{oi}$ implied by

$$\pi^R_{oi}(\hat{z}^R_{oi}\phi^R_{oi}) = f^R_{oi}W^h_i. \tag{4}$$

Discussion on the differentiated variety assumption. In characterizing R&D decisions, we treat a firm's decisions at different hosts as independent. This independence stems from the assumption that varieties developed at different R&D centers of the same firm are differentiated from each other.[14] This assumption is consistent with how R&D is organized in many conglomerates. For example, General Electric organizes research labs across five countries (U.S., China, Germany, India, Brazil) by scientific discipline. It also accords with the fact that many MNCs are formed via mergers and acquisitions between existing firms with own products.[15, 16]

I test this assumption in the Supplementary Appendix. Specifically, I show that affiliate invention responds to the R&D subsidies, availability of researchers, and IPR protection of the host, but *not* to these factors in either the headquarters or other countries where the firm operates. This suggests interdependence among R&D centers is not a first-order feature of my data.

One may be skeptical whether all varieties from *the same* R&D center can be reasonably assumed to be differentiated from each other, or whether all R&D is for new varieties. I show in Appendix B.1 that the current horizontal innovation setup is isomorphic to a setup in which firms create *one* new variety by building an offshore R&D center and then recruit researchers to improve the quality of *that* variety, with γ being the elasticity of product quality in researchers' input.

[14] An alternative setup that retains tractability without imposing independence is to assume there is no fixed R&D cost and that firms choose the location for each R&D task according random efficiency draws. Without fixed costs, however, such alternatives might not fully capture variations in the entry decisions documented in Section 2.3.

[15] More than 70% of FDI flows in the data are in the form of mergers and acquisitions (Nocke and Yeaple, 2008). Our model would rationalize this as firms transferring knowhow to newly acquired foreign firms, which have their own brands and products, and help them carry out independent product development and manufacturing production.

[16] In addition to treating R&D at affiliates symmetrically with each other, the model also treats it symmetrically with R&D at headquarters. It is possible that firms carry out more fundamental knowhow-building R&D at the headquarters. An extension of this model that allows firms to first invest in R&D to build up 'core management capacity' before performing product innovation at home and abroad would be consistent with this pattern. My quantitative experiments based on the current setup can be viewed as a short-term version of that model.

3.3 Production and Trade

I now explain firms' production and trade decisions. After a variety ω is developed, the firm first obtains N idiosyncratic location-specific efficiency draws for its production, denoted by $\boldsymbol{\eta}(\omega) = (\eta_1(\omega), \eta_2(\omega), .., \eta_N(\omega))$, and then decides whether to sell ω to each country. Entry to country d for *each variety* costs f_d^M efficiency units of high-skill labor, which I interpret as product-specific advertisement cost. After paying this cost, the firm chooses the cheapest production location for ω. Production takes only low-skill labor. For a variety developed in country i by a firm from country o, the marginal cost of selling to country d through production in m is $\frac{W_m^l \tau_{md}}{T_m \phi_{oim}^P \eta_m(\omega)}$, where W_m^l is the low-skill wage in country m, T_m is the country-wide manufacturing efficiency that captures the influence of infrastructure, institution, etc., and τ_{md} is the iceberg trade cost from m to d. $\phi_{oim}^P \leq 1$ captures the frictions of multinational production. Motivated by Facts 2 and 3, I will parameterize ϕ_{oim}^P to be a function of both the distance between o and m and the distance between i and m, allowing proximity to both headquarters and R&D centers to play a role.

As production involves no fixed costs, for each destination, the firm chooses the country with the lowest cost to produce ω. Under the optimal pricing, the price of ω in country d is

$$p_{oid}(\omega) = \frac{\sigma}{\sigma - 1} \cdot \min_m \{ \frac{W_m^l \tau_{md}}{T_m \phi_{oim}^P \eta_m(\omega)} \}.$$

The revenue and operation profit from variety ω in market d is, respectively,

$$\begin{aligned} r_{oid}(\omega) &= \mathbb{1}(p_{oid}(\omega) < \hat{p}_d) \cdot X_d / P_d^{1-\sigma} \cdot p_{oid}(\omega)^{1-\sigma} \\ \pi_{oid}(\omega) &= \mathbb{1}(p_{oid}(\omega) < \hat{p}_d) \cdot [\frac{1}{\sigma} X_d / P_d^{1-\sigma} \cdot p_{oid}(\omega)^{1-\sigma} - f_d^M W_d^h], \end{aligned}$$

where $\hat{p}_d \equiv \left(\frac{\sigma W_d^h f_d^M}{X_d} \right)^{\frac{1}{1-\sigma}} P_d$ is the cutoff price below which a firm can sell enough to recoup $f_d^M W_d^h$. By writing $r_{oid}(\omega)$ and $\pi_{oid}(\omega)$ as dependent on $\mathbb{1}(p_{oid}(\omega) < \hat{p}_d)$, these expressions take into account that the firm only sell ω to market d if $\boldsymbol{\eta}(\omega)$ draws are sufficiently favorable.

For tractable aggregation, as in ARRY, I make the following parametric assumption:

Assumption 1.

$$a) \quad H(\boldsymbol{x}|z^P) \equiv Prob(\eta_1 \leq x_1, ..., \eta_N \leq x_N) = \begin{cases} 1 - \Big(\sum_{m=1}^{N} (z^P / x_m)^\theta / N \Big), \forall m \in \{1, ...N\}, \; x_m \geq z^P \\ 0, \; \exists m \in \{1, ..., N\}, \; x_m < z^P \end{cases}$$

$$b) \quad \hat{p}_d < \frac{1}{z^P} \frac{\sigma}{\sigma - 1} W_m^l \tau_{md} / (T_m \phi_{oim}^P), \; \forall \; o, \; i, \; m, \; d, \; \forall z^P > 0.$$

Assumption 1.a specifies the distribution for $\boldsymbol{\eta}(\omega)$. As $H(\boldsymbol{x}|z^P)$ increases in z^P, firms with a higher z^P on average receive better draws. The parametric form of $H(\boldsymbol{x}|z^P)$ has two attractive implications. First, $[p_{oid}(\omega|z^P)]^{1-\sigma}$ follows a Pareto distribution.[17] Second, together with Assump-

[17]More precisely, $[p_{oid}(\omega|z^P)]^{1-\sigma}$ follows a Pareto *away* from its minimum support. Assumption 1.b implies that

tion 1.b, it implies that the expected share of the sales of ω in country d that is fulfilled through production in country m, denoted by ψ_{oimd}, is

$$\psi_{oimd} = \frac{1}{N}(\frac{T_m \phi^P_{oim}}{W^l_m \tau_{md}})^\theta / \tilde{\zeta}^\theta_{oid}, \text{ where } \tilde{\zeta}_{oid} \equiv [\sum_m \frac{1}{N}(\frac{T_m \phi^p_{oim}}{W^l_m \tau_{md}})^\theta]^{\frac{1}{\theta}}. \quad (5)$$

Let $\overline{r}_{oid}(z^P)$, $\overline{\pi}_{oid}(z^P)$, and $\overline{f}^M_{oid}(z^P)$ denote the expected values (over $\boldsymbol{\eta}$) of *per-variety* revenue, operation profit, and marketing cost associated with market d for varieties from an R&D center with z^P. These objects are given by:

$$\begin{aligned} \overline{r}_{oid}(z^P) &\equiv \mathbb{E}\big(r_{oid}(\omega)|z^P\big) = \frac{\theta(\sigma-1)^\theta \sigma^{1-\frac{\theta\sigma}{\sigma-1}}}{\theta-(\sigma-1)} X_d^{\frac{\theta}{\sigma-1}} P_d^\theta (W^h_d f^M_d)^{\frac{\theta+1-\sigma}{1-\sigma}} (\tilde{\zeta}_{oid} z^P)^\theta \quad (6)\\ \overline{f}^M_{oid}(z^P) &\equiv \mathbb{E}\big(f^M_{oid}(\omega)|z^P\big) = \frac{\theta-(\sigma-1)}{\theta\sigma}\overline{r}_{oid}(z^P)\\ \overline{\pi}_{oid}(z^P) &\equiv \mathbb{E}\big(\pi_{oid}(\omega)|z^P\big) = \frac{1}{\sigma}\overline{r}_{oid}(z^P) - \overline{f}^M_{oid}(z^P). \end{aligned}$$

The total operation profit from a variety by an R&D center in country i is

$$\overline{\pi}_{oi}(z^P) = \sum_d \overline{\pi}_{oid}(z^P). \quad (7)$$

Implications for the spatial patterns of R&D and production. To understand how the model accounts for the documented spatial patterns of R&D and production within a firm, consider a firm from o with R&D centers in a set of countries denoted by $\boldsymbol{R}$. Let the efficiency and R&D team size of the firm in these countries be $\{(z^R_i, z^P_i)|i \in \boldsymbol{R}\}$ and $\{h_{oi}(z^R_i, z^P_i)|i \in \boldsymbol{R}\}$, respectively. Let the total production of the firm in location m across all its products be $r_{om}(\boldsymbol{z}^R, \boldsymbol{z}^P)$. Combining (1), (5), and (6) gives us

$$r_{om}(\boldsymbol{z}^R, \boldsymbol{z}^P) \propto \left[(\frac{T_m}{W^l_m})^\theta\right] \times \left[\sum_d \frac{X_d^{\frac{\theta}{\sigma-1}} P_d^\theta (W^h_d f^M_d)^{\frac{\theta+1-\sigma}{1-\sigma}}}{(\tau_{md})^\theta}\right] \times \Big[\sum_{i\in \boldsymbol{R}} [h_{oi}(z^R_i, z^P_i)]^\gamma (z^P_i)^\theta z^R_i (\phi^P_{oim})^\theta\Big]. \quad (8)$$

This expression shows affiliate production at m depends on three factors: production cost (the first bracket), and the access of m to markets (the second bracket) and to the *global* R&D portfolio of the firm (the third bracket). Through the third term, MP frictions $\{\phi^P_{oim}\}$ modulate the allocation of production in relationship to the headquarters and where R&D takes place, allowing the model to speak to Facts 2 and 3.

Using U.S. data, Bilir and Morales (2020) find that headquarters R&D improves affiliate performance, while affiliate R&D has little impact on sibling affiliates. To connect my setup to this

among firms actively selling to d, that minimum support does not bind. The substance of this assumption is that f^M_d is large so that when the realization of $\boldsymbol{\eta}(\omega)$ is low enough, firms do not enter d. As long as this condition holds, the exact value of f^M_d matters very little.

finding, note that the elasticity of production in m w.r.t. R&D at country i, denoted by ϵ_{oim}, is

$$\epsilon_{oim} \equiv \frac{\partial \log\left(r_{om}(\mathbf{z}^R, \mathbf{z}^P)\right)}{\partial \log\left(h_{oi}(z_i^R, z_i^P)\right)} = \gamma \times \frac{[h_{oi}(z_i^R, z_i^P)]^\gamma (z_i^P)^\theta z_i^R (\phi_{oim}^P)^\theta}{\sum_{i' \in \mathbf{R}} [h_{oi'}(z_{i'}^R, z_{i'}^P)]^\gamma (z_{i'}^P)^\theta z_{i'}^R (\phi_{oi'm}^P)^\theta}. \tag{9}$$

Loosely speaking, ϵ_{oim} is the researcher elasticity in R&D (γ) multiplied by a ratio that captures the importance of R&D in i for production in country m. If firms conduct the majority of their R&D at the headquarters (85% of the R&D by U.S. MNCs takes place in the U.S.) or are more efficient at home (i.e., for $o \neq i$, $z_o^R > z_i^R$ and $z_o^P > z_i^p$), then headquarters R&D will be more important for affiliate production, implying that a marginal increase in headquarters R&D will leads to a larger increase in affiliate output. Related, if separating production from innovation is costly, i.e., for $m \neq i, o$, $\phi_{oii}^P >> \phi_{oim}^P$, then a marginal increase in R&D spending in an affiliate i will have a negligible effect on output in $m \neq i$. My calibration finds support for these premises and implies that affiliates' output elasticity to headquarters R&D is on average three times its elasticity to the combined R&D of all other affiliates.[18] These implications are in line with Bilir and Morales (2020).

Following the above discussion, γ and ϕ_{oim}^P determine the impacts of a marginal increase in R&D in one of the firm's locations on the local and global performance of the firm. In general equilibrium counterfactuals, in addition to these channels, we also need to account for how firms and workers re-optimize in response to a change in the economy, and how these decisions aggregate. I now close the model in order to conduct such counterfactuals.

3.4 Aggregation

The cutoff entry rule for offshore R&D implies the measure of R&D centers from o to i is $R_{oi} \equiv E_o \cdot \left(1 - G_o^E(\hat{z}_{oi}^R)\right)$. The cdf of the innovation efficiency of these R&D centers, denoted G_{oi}^R, is

$$G_{oi}^R(z^R) = \frac{1}{R_{oi}} \mathbb{1}(z^R > \hat{z}_{oi}^R \phi_{oi}^R) \cdot E_o \cdot G_o^E\left(z^R / \phi_{oi}^R\right).$$

Let $V_{oi}(z^P)$ be the marginal density of varieties invented in country i by R&D centers from country o with production efficiency z^P, i.e.,

$$V_{oi}(z^P) = R_{oi} \int_0^\infty v_{oi}(z^P, z^R) \cdot g(z^P | z^R) \cdot dG_{oi}^R(z^R), \tag{10}$$

[18] Under my calibration, affiliate production on average consists of 46% headquarter R&D, 39% local R&D, and 15% from all sibling R&D combined. Thus, offshore R&D makes a positive, although quantitatively small, contribution to output at sibling affiliates. I explore in Appendix C.3 a setting where varieties invented in overseas affiliates cannot be produced in other affiliates, thereby eliminating such 'bridge' R&D. This alternative model, when calibrated to match the data, implies similar impacts of offshore R&D on the gains from openness.

where $v_{oi}(z^P, z^R)$ is given by equation (2). The total measure of varieties across all z^P and the price index are given by, respectively,

$$V_{oi} = \int_0^\infty V_{oi}(z^P)dz^P \tag{11}$$
$$P_d^{1-\sigma} = \theta(\frac{\sigma}{\sigma-1})^{-\theta}\frac{1}{\theta-(\sigma-1)}\Big(\frac{\sigma W_d^h f_d^M}{X_d}\Big)^{\frac{\theta-(\sigma-1)}{1-\sigma}} P_d{}^{\theta-(\sigma-1)}\sum_o\sum_i \tilde{\zeta}_{oid}^\theta \int_0^\infty (z^P)^\theta V_{oi}(z^P)dz^P.$$

The sales to country d of the varieties developed in i by firms from o, denoted by X_{oid}, is

$$X_{oid} = \theta(\frac{\sigma}{\sigma-1})^{-\theta}\frac{1}{\theta-(\sigma-1)}(\sigma W_d^h f_d^M)^{\frac{\theta-(\sigma-1)}{1-\sigma}}\Big(\frac{X_d}{P_d^{1-\sigma}}\Big)^{\frac{\theta}{\sigma-1}}\tilde{\zeta}_{oid}^\theta\int_0^\infty (z^P)^\theta V_{oi}(z^P)dz^P. \tag{12}$$

Among theses sales, let X_{oimd} be the value fulfilled through production in country m. Because equation (5) holds for each variety making up X_{oid}, it applies to the aggregate flows, i.e.,

$$X_{oimd} = \psi_{oimd}X_{oid}.$$

Sales revenue is split among participants at different stages. First, the low-skill labor value added in production. Letting Y_{om} denote the low-skill value added in m for firms from o, we have

$$Y_{om} = \frac{\sigma-1}{\sigma}\sum_{i,d}X_{oimd}$$

The markup ($1/\sigma\sum_{i,d}X_{oimd}$) covers the marketing cost in destination d, the R&D expenses in country i, and the net profit to firm owners at o. Let F_{od}^M be the total marketing cost incurred in d by firms from o, I_{oi} be the R&D expenses in product development in i and Π_{oi} be the profits from these products, and F_{oi}^R be the fixed R&D cost in country i, we have

$$F_{od}^M = 1/\sigma\cdot[1-(\sigma-1)/\theta]\sum_{i,m}X_{oimd}$$
$$\Pi_{oi} = (1-\gamma)(\sigma-1)/(\sigma\theta)\cdot\sum_{m,d}X_{oimd}$$
$$I_{oi} = \gamma/(1-\gamma)\cdot\Pi_{oi}$$
$$F_{oi}^R = E_o\cdot[1-G_o^E(\hat{z}_{od}^R)]\cdot f_{oi}^R W_i^h.$$

The labor market clearing condition for low- and high-skill workers are, respectively

$$W_d^l L_d^l = \sum_o Y_{od}, \qquad \text{and} \qquad W_d^h L_d^h = \sum_o I_{od} + \sum_o F_{od}^M + \sum_o F_{od}^R.$$

The consumption expenditures X_d is the sum of total labor income and net profit, given by

$$X_d = W_d^h L_d^h + W_d^l L_d^l + \sum_i(\Pi_{di} - F_{di}^R). \tag{13}$$

Appendix B.3 summarizes the system of equations that characterize the competitive equilibrium.

3.5 Special Cases

Using special cases, I illustrate how geography and endowment affect offshore R&D, and how offshore R&D interacts with trade and MP. Country specialization in innovation versus production plays a key role in mediating the effects. To fix ideas, I define specialization as the ratio of a country's labor income from R&D over that from production ($\frac{\sum_o I_{oi}+\sum_{o\neq i} F_{oi}^R}{\sum_o Y_{om}}$). In the absence of MP and offshore R&D, $\sum_{o\neq i} F_{oi}^R = 0$ and $\frac{\sum_o I_{oi}}{\sum_o Y_{om}} = \frac{\gamma}{\theta}\frac{\sum_{o,m,d} X_{oimd}}{\sum_{o,i,d} X_{oimd}} = \frac{\gamma}{\theta}\frac{\sum_{o,m,d} X_{ommd}}{\sum_{o,i,d} X_{oiid}} = \frac{\gamma}{\theta}$, so countries have the same specialization. With MP, as shown below, endowment and geography, moderated by offshore R&D, jointly determine specialization. Throughout this subsection, I assume that marketing cost (f_d^M) is either paid in the final goods or zero ($\theta \to \sigma - 1$). As most proofs follows closely the intuition discussed, they are relegated to the Supplementary Appendix.

3.5.1 The Role of Geography

Through three special cases, I first examine how geography affects offshore R&D. Each of these cases isolates one role of geography.

Proposition 1. *1. **The role of access to foreign knowhow with frictionless trade and offshore production.** Assume that trade and offshore production are both frictionless ($\phi_{oim}^P = \tau_{md} = 1$ $\forall o, i, m, d$). In a multi-country economy, consider two focal countries, i and i', that differ only in that foreign knowhow can be more easily transferred to i than to i'. Then compared to i', i specializes in R&D and has a higher share of domestic R&D at foreign firms.*

*2. **The role of access to foreign producers with frictionless trade.** Assume that trade is frictionless and that the proximity to headquarters does not matter for the production efficiency, i.e., $\forall o \neq i$, $\phi_{oim}^P = \phi_{iim}^P$. In a multi-country economy, consider focal countries i and i' that differ only in that inventions in country i can be produced in other countries with higher efficiency ($\forall m \neq i, i'$, $\phi_{oim}^P > \phi_{oi'm}^P$). Then compared to i', i specializes in R&D and has a higher share of domestic R&D at foreign firms.*

*3. **The role of access to foreign consumers with frictionless offshore production.** Assume that offshore production is frictionless. In a multi-country economy, consider focal countries i and i' that differ only in that country i has higher exporting costs for other destinations ($\forall d \neq i, i'$, $\tau_{id} > \tau_{i'd}$). Then compared to i', i specializes in R&D and has a higher share of domestic R&D at foreign firms.*

The first case says that hosts close to countries relatively abundant in knowhow tend to attract more offshore R&D and, as a result, specialize in innovation. The second and the third cases show a somewhat subtle role of host market access. In partial equilibrium, both the access to foreign producers through MP and the access to foreign consumers through export increase the return of doing R&D in a host. In general equilibrium, however, these two types of access have the opposite effects. Whereas better access to producers pushes a host to specialize in innovation, better access to consumers—akin to higher manufacturing productivity—pushes it to specialize in production, increasing the overall wage and making R&D there less profitable.[19] In both cases, the change in R&D incentives has a stronger effect on the R&D by foreign firms as they also respond in the extensive margin. This results in changes in the share of domestic R&D at foreign firms.

3.5.2 The Role of Endowment Distributions

I next explore how knowhow and talent distributions shape specialization and offshore R&D.

Proposition 2. *In a multi-country economy with frictionless MP, consider two focal countries i and i' that do not engage in offshore R&D between each other (i.e., $\phi^R_{ii'} = \phi^R_{i'i} = 0$) but may engage in offshore R&D with other countries as both the host and the headquarters.*

1. *If i and i' differ only in that $A_i(\alpha)$ first-order stochastically dominates $A_{i'}(\alpha)$, then i has a higher share of domestic R&D at foreign firms.*

2. *If i and i' differ only in that i has more domestic knowhow, then i has a lower share of domestic R&D at foreign firms. Domestic knowhow is defined as $E_i \int_0^\infty [\int_0^\infty (z^R)^{\frac{1}{1-\gamma}} (z^P)^{\frac{\theta}{1-\gamma}}] dG^P(z^P|z^R) dG^E_i(z^R)$.*

3. *Suppose that trade is frictionless, that the fixed offshore R&D cost in i and i' is zero, and that $A_i(\alpha)$ and $A_{i'}(\alpha)$ are Pareto distributions with the same tail parameter and different minimum supports, denoted by $\underline{\alpha}_i$ and $\underline{\alpha}_{i'}$ respectively. Then compared to i', country i specializes in R&D if and only if*

$$\underbrace{\frac{(T_i)^\theta / L_i}{(T_{i'})^\theta / L_{i'}}}_{\text{manufacturing productivity}} \cdot \underbrace{\left(\frac{Z_i / L_i}{Z_{i'} / L_{i'}}\right)^{-(1+\theta)(1-\gamma)}}_{\text{knowhow access}} \cdot \underbrace{\left(\frac{\underline{\alpha}_i}{\underline{\alpha}_{i'}}\right)^{-\gamma(1+\theta)}}_{\text{Talent}} < 1, \tag{14}$$

where $Z_i \equiv \sum_o E_o (\phi^R_{oi})^{1-\gamma} \int_0^\infty (z^R)^{\frac{1}{1-\gamma}} [\int_0^\infty (z^P)^{\frac{\theta}{1-\gamma}} dG^P(z^P|z^R)] dG^E_o(z^R)$.

The first two cases show that offshore R&D can arise from the spatial disparities in knowhow and talent endowment, flowing from countries abundant in knowhow to those abundant in talent. The third case demonstrates how countries' endowment, moderated by offshore R&D, shape international specialization. Countries with better talent (large $\underline{\alpha}_i$), lower size-adjusted manufacturing efficiency ($(T_i)^\theta / L_i$), or better access to global knowhow (Z_i / L_i) tend to specialize in R&D. Echoing the first case of Proposition 1, for countries whose Z_i is mainly from foreign sources, offshore R&D plays an important role in specialization.

3.5.3 The Interaction between Offshore R&D and Other Forms of Globalization

Lastly, I explore how offshore R&D interacts with trade and MP.

Proposition 3. *In a world with two countries, i and i', assume that trade is frictionless, that fixed offshore R&D costs are zero and offshore R&D efficiency is impractically low ($\phi^R_{ii'} = \phi^R_{i'i} = 0$), and that $A_i(\alpha)$ and*

[19] This is related to the 'anti-home-market effect' discussed in the working paper version of ARRY. The main difference here is that such effect also affects and interacts with offshore R&D.

$A_{i'}(\alpha)$ are Pareto distributions with the same tail parameter. Consider a small unilateral increase in $\phi^R_{ii'}$ from two otherwise identical baseline economies: one with frictionless MP and one where MP is infeasible.

The increase in offshore R&D from i to i' due to the change, measured using total inventions in i' by affiliates of firms from i, is larger in the baseline economy with frictionless MP if and only if in that baseline economy, country i specializes in production and country i' in R&D.

In both economies, larger $\phi^R_{ii'}$ encourages offshore R&D in i', enhancing its innovation efficiency. Whether the presence of MP amplifies or dampens this effect depends on the initial specialization of i'. If MP enables i' to specialize in R&D, then the change induced by a larger $\phi^R_{ii'}$ is aligned with this initial specialization. In this case, offshore R&D strengthens $i's$ comparative advantage and complements MP. If the opposite as true, then the change induced by larger $\phi^R_{ii'}$ is partially offset by the specialization enabled by MP, so the increase in offshore R&D will be dampened.

The impact of such interactions on welfare can be seen through limit cases. When $T_{i'} \to 0$, with MP, i' will specialize in innovation and without it, i' will not be able to produce anything. Thus, increasing $\phi^R_{ii'}$ would bring benefits to i and i' only when MP is feasible. In this case, MP increases the gains from offshore R&D. On the other hand, when $T_i \to 0$ and $E_{i'} \to 0$, the gains from offshore R&D can be arbitrarily large when MP is infeasible but are bounded when MP is frictionless. In this case, the presence of MP decreases the gains from offshore R&D.

3.6 The Gains from Openness

Before turning to quantification, I explore how offshore R&D affects the welfare implications of globalization. I focus on the gains from openness, which is characterized in Proposition 4.

Proposition 4. *Assume that firms' z^P draws are independent of z^R, that the supply of high- and low-skill labor is exogenous, and that firms' innovation efficiency $\tilde{z}^R$ follows a Pareto distribution with a country-specific minimum support.*[20] *The gains from openness, defined as the change in real income $\frac{X_d}{P_d}$ as d moves from complete isolation to the observed equilibrium, is*

$$\underbrace{\left(\frac{X_{dddd}}{\sum_m X_{ddmd}}\right)^{-\frac{1}{\theta}} \times \left(\frac{\sum_{o,m} X_{odmd}}{X_d}\right)^{-\frac{1}{\theta}} \times \left(\frac{\sum_m X_{ddmd}}{\sum_{o,m} X_{odmd}}\right)^{-\frac{1}{\theta}} \times \left(\frac{I_{dd}}{\sum_o I_{od}}\right)^{\frac{\gamma}{\theta}}}_{\text{direct effect}} \quad \underbrace{\times \frac{X_d}{Y_d}}_{\text{indirect income effect}} \quad \underbrace{\times f\left(\frac{\sum_o I_{od}}{X_d}, \frac{I_{dd}}{\sum_o I_{od}}\right)}_{\text{indirect price effect}} \tag{15}$$

where $f(\frac{\sum_o I_{od}}{X_d}, \frac{I_{dd}}{\sum_o I_{od}})$ is a function of model parameters and two ratios: the share of variable R&D expenditures in income $\frac{\sum_o I_{od}}{X_d}$, and the share of these expenditures at domestic firms $\frac{I_{dd}}{\sum_o I_{od}}$.

Expression (15) decomposes the gains from openness into various components. The first four terms jointly capture the direct impact of openness on the real wages of production workers, *holding constant* the composition of national income from different sources. Among these terms, $\frac{X_{dddd}}{\sum_m X_{ddmd}}$ measures the importance of trade. $\frac{\sum_{o,m} X_{odmd}}{X_d}$, the fraction of country d expenditure on goods

[20] The first part of the assumption rules out positive correlation between z^P and z^R at the firm level. On the other hand, z^P can be from any distributions and differ across pairs of origin and host countries, so heterogeneity at country-pair level and the headquarter effects on z^P are both allowed.

invented in d, captures the benefit from having access to goods invented elsewhere through trade, MP, or both. The first two terms capture the combined impact of trade and MP. The third term $\frac{\sum_m X_{ddmd}}{\sum_{o,m} X_{odmd}}$ measures the importance of foreign firms in domestic R&D. The smaller is this term, the more country d depends on and benefits from the R&D foreign affiliates. This benefit, however, is partially offset by the crowd-out effect of foreign R&D on domestic firms, the strength of which is summarized by the share of variable R&D at local firms, $(\frac{I_{dd}}{\sum_o I_{od}})^{\frac{\gamma}{\theta}}$.

The indirect effects reflect the influence of MNC activities on welfare through the composition of national income. First, the ratio between total and manufacturing income $\frac{X_d}{Y_d}$ captures how the activities of MNCs affect the distribution of the innovation rent—including the profit to firms and the income to researchers—across countries. This redistribution can increase the total income beyond the gains in the real wage of production workers for countries with higher $\frac{X_d}{Y_d}$ than in autarky—those that specialize in innovation or are the main exporters of knowhow; it can have the opposite effect for countries that specialize in production. Second, openness affects the share of high-skill workers in R&D versus marketing, which can increase or decrease the domestic variety availability. This channel is summarized by two sufficient statistics, the fraction of research at domestic firms $\frac{I_{dd}}{\sum_o I_{od}}$ and the share of national income from product development $\frac{\sum_o I_{od}}{X_d}$. We denote this channel by $f(\frac{\sum_o I_{od}}{X_d}, \frac{I_{dd}}{\sum_o I_{od}})$.

To connect my model to existing studies, consider the special case without offshore R&D, in which expression (15) becomes

$$\underbrace{(X_{dddd}/\sum_m X_{ddmd})^{-\frac{1}{\theta}} \times (\sum_{o,m} X_{odmd}/X_d)^{-\frac{1}{\theta}} \times 1 \times 1}_{=(\sum_o X_{oddd}/X_d)^{-\frac{1}{\theta}} \text{ in the absence offshore R\&D}} \times (X_d/Y_d) \times f(X_d/Y_d) - 1. \tag{16}$$

There are two differences in this special case. First, the direct effect collapses to $(\frac{\sum_o X_{oddd}}{X_d})^{-\frac{1}{\theta}}$, which is also a special case of ARRY and Ramondo and Rodríguez-Clare (2013). Second, the indirect price effect $f(\frac{\sum_o I_{od}}{X_d}, \frac{I_{dd}}{\sum_o I_{od}})$ now takes a simpler form and depends solely on the ratio between total income over manufacturing income $\frac{X_d}{Y_d}$.

Comparing (15) and (16) illustrates how offshore R&D affects the gains from openness. First and foremost, it introduces a direct effect on domestic invention captured in the third and fourth terms of (15). To gauge the importance of this effect, consider a special case with ϕ^P_{oim} independent of i, in which case $\frac{\sum_m X_{ddmd}}{\sum_{o,m} X_{odmd}} = \frac{\sum_{i,m} X_{dimd}}{\sum_{o,i,m} X_{oimd}} = \frac{I_{dd}}{\sum_o I_{od}}$, so the net effect is $(\frac{I_{dd}}{\sum_o I_{od}})^{-\frac{1-\gamma}{\theta}}$. The median country in my sample has about 30% of its R&D done at foreign affiliates. For $\gamma = 0.25$ and $\theta = 4.5$, $(\frac{I_{dd}}{\sum_o I_{od}})^{-\frac{1-\gamma}{\theta}} \approx 1.05$, implying about 5% direct gains from offshore R&D. Second, the gains from trade and offshore production $(\frac{X_{dddd}}{\sum_m X_{ddmd}})^{-\frac{1}{\theta}} \times (\frac{\sum_{o,m} X_{odmd}}{X_d})^{-\frac{1}{\theta}}$ and the indirect effect $f(\frac{\sum_o I_{od}}{X_d}, \frac{I_{dd}}{\sum_o I_{od}})$ also differ from their counterparts in expression (16). Because of these differences, researchers seeing the same data would infer different welfare gains if offshore R&D is omitted.

Somewhat more subtle, expression (15) also shows that four-way flow data $\{X_{oimd}\}$ are needed for evaluating the gains from openness. As such data are not systematically collected, researchers often have to infer the ratios in (15) using *bilateral* trade and MP data (see de Gortari, 2019 for a discussion of this approach in the context of trade in goods.) This inference can be biased if offshore R&D and its connection to MP is overlooked, resulting in incorrect welfare assessments. I will return to this point in quantification.

4 Parameterization

I parameterize the model using firm and aggregate data, focusing on the same 37 countries as in Section 2. This section describes the main parameterization procedures; additional information about the data and the calibration procedures is relegated to Appendix C.

4.1 Additional Assumptions

I start by describing the functional form assumptions.

Talent and innovation efficiency distributions. I parameterize the ability distribution for workers in country i, $A_i(\alpha)$, to be log normal, i.e., $\log(a_i) \sim N(\mu_\alpha^i, {\sigma_\alpha^i}^2)$.

I assume that firms' innovation efficiency is drawn from a truncated Pareto distribution:

$$G_o^E(\tilde{z}^R) = \frac{(\underline{Z}_o^R)^{-\kappa_o^R} - (\tilde{z}^R)^{-\kappa_o^R}}{\underline{Z}_o^{R^{-\kappa_o^R}} - \overline{Z}_o^{R^{-\kappa_o^R}}}, \tag{17}$$

where $\underline{Z}_o^R$ and $\overline{Z}_o^R$ are the lower and upper bounds of the support and κ_o^R is the tail coefficient, all of which can vary by country.[21]

Relationship between z^P and z^R. I assume that $G(z^P|z^R)$, the cdf of z^P, is given by:

$$G(z^P|z^R) = \text{Prob}(z^P \in H|z^R) \cdot G_H^P(z^P) + [1 - \text{Prob}(z^P \in H|z^R)] \cdot G_L^P(z^P), \tag{18}$$

in which $G_H^P(z^P)$ and $G_L^P(z^P)$ are two distributions (high and low) from which firms draw z^P. The probability of drawing from the high distribution increases in z^R:

$$\text{Prob}(z^P \in H|z^R) = \frac{\exp(\delta_0 + \delta_1 \times z^R)}{1 + \exp(\delta_0 + \delta_1 \times z^R)}. \tag{19}$$

δ_0 and δ_1 are to be estimated. Positive δ_1 means that innovative firms tend to be more productive on average. $G_H^P(z^P)$ and $G_L^P(z^P)$ are both Pareto distributions with different supports:

$$G_H^P(z^P) = 1 - (\frac{\underline{z}_H^P}{z^P})^{\kappa_P}, \quad G_L^P(z^P) = 1 - (\frac{\underline{z}_L^P}{z^P})^{\kappa_P}, \qquad \underline{z}_L^P < \underline{z}_H^P.$$

Specifying $G(z^P|z^R)$ as in equation (18) makes the model tractable as it circumvents the need for numerically integrating over the two dimensional (z^P, z^R) space (see equations (10) and (11)).

Geographic frictions. I parameterize the frictions impeding offshore production and R&D as

[21] I choose the truncated Pareto over the conventional Pareto because the firm-level management survey that I use to discipline the distributional parameters is not very large. This makes it less ideal for disciplining Pareto distributions, in which firms at the extreme right tail play an out-sized role. It turns out that the truncated Pareto distribution fits the right tail of the firm size distribution well, see Table 6.

log linear functions of various distance measures and host-specific barriers as follows:

$$\begin{cases} \log(\phi^P_{oim}) = s \cdot \log(\phi^P_{im}) + (1-s) \cdot \log(\phi^P_{om}),\ s \in [0,1], \text{ where} \\ \log(\phi^P_{om}) = \mathbb{1}(o \neq m) \cdot [\phi^P_m + \overrightarrow{\beta^{P,om}} \cdot \overrightarrow{dist_{om}}] \\ \log(\phi^P_{im}) = \mathbb{1}(i \neq m) \cdot [\phi^P_m + \overrightarrow{\beta^{P,im}} \cdot \overrightarrow{dist_{im}}] \end{cases} \tag{20}$$
$$\begin{cases} \log(\phi^R_{oi}) = \mathbb{1}(o \neq i) \cdot [\phi^R_i + \overrightarrow{\beta^R} \cdot \overrightarrow{dist_{oi}}] \\ f^R_{oi} = \mathbb{1}(o \neq i) \cdot \exp\left(\phi^{fR}_i + \overrightarrow{\beta^{fR}} \cdot \overrightarrow{dist_{oi}}\right) \end{cases}$$

The first block of (20) defines ϕ^P_{oim}, the retained production efficiency in country m, as the geometric average of ϕ^P_{im} and ϕ^P_{om}. Both ϕ^P_{om} and ϕ^P_{im} are functions of ϕ^P_m, which captures host-specific barriers to inward offshore production, and bilateral distance measures $\overrightarrow{dist_{om}}$ and $\overrightarrow{dist_{im}}$. Following Tintelnot (2016), I include four distance measures: geographic distance and indicators for whether the two countries share an official language, are adjacent, or have a colonial tie. Parameter s captures the importance of the proximity to headquarters versus R&D centers in production. If only the proximity to headquarters matter ($s = 0$), varieties invented by affiliates would be produced near the home country; on the other hand, if $s = 1$, these varieties would be mostly produced locally. The four-way flows $\{X_{oimd}\}$ under these two cases cross borders with different intensity and can lead to different welfare measurements, as I show below.

The second block of (20) defines the retained efficiency and the fixed cost in offshore R&D, ϕ^R_{oi} and f^R_{oi}. Through the inclusion of ϕ^R_i and ϕ^{fR}_i, the parameterization allows differential openness to foreign R&D across hosts. Finally, the indicator functions in these definitions normalize ϕ^P_{om}, ϕ^R_{oi}, ϕ^P_{im} to 1 and f^R_{oi} to zero for domestic activities.

Discussion on the role of different parameters. Before proceeding to calibration, I discuss how different parameters affect the models' outcomes. Parameters in the model fall into three broad categories. The first is the structural elasticities, $\{\gamma, \theta, \sigma\}$, that shape the composition of markup, marketing cost, and R&D in firms' revenue. For firms operating only in one country, these parameters determine how a marginal increase in R&D affects their local profit and sales. The second is the geographic parameters in (20). As shown in equation (8), they determine how an increase in R&D affects firms' global output and profit. Lastly, for general equilibrium counterfactuals, I need to aggregate across firms and account for the changes in workers' choices and other equilibrium outcomes. The remaining parameters essentially discipline the importance of these forces.

4.2 Parameters Assigned Directly

Some parameters of the model are set externally. Table 3 lists these parameters and their values.

Elasticities. I set the elasticity of substitution between varieties σ to 4, which implies around 33% markups, in line with recent estimates (e.g., De Loecker and Eeckhout, 2018). From equation (6), the share of sales devoted to marketing is $\frac{\theta-(\sigma-1)}{\theta\sigma}$. According to a recent survey of chief marketing officers in the U.S.,[22] firms spend around 8-10% of revenues on marketing. I set $\theta = 4.5$ so marketing accounts for 8.3% of sales. This value is close to the estimate by ARRY. With θ and σ given, γ determines the share of sales spent on developing new varieties ($\frac{\gamma(\sigma-1)}{\theta\sigma}$), which I calibrate to match the revenue share of R&D expenses. Compustat U.S. manufacturing firms on average spend 4% of sales on R&D. I set $\gamma = 0.25$ so that $\frac{\gamma(\sigma-1)}{\theta\sigma} \approx 0.04$.

Trade costs. I normalize $\tau_{mm} = 1$ and assume symmetric trade costs. As shown in Appendix C.2, the Head and Ries (2001) approach applies to this model, and we can express trade costs as:

$$\tau_{md} = \tau_{dm} = \left(\frac{\sum_{o,i} X_{oimd}}{\sum_{o,i} X_{oimm}} \cdot \frac{\sum_{o,i} X_{oidm}}{\sum_{o,i} X_{oidd}}\right)^{-\frac{1}{2\theta}}.$$

Although X_{oimd} is not observable, the four summations in the expression are observable from the World Input Output Database (Timmer et al., 2016), which I use to recover τ_{md}.

Labor endowment. As patenting and trade are largely a manufacturing activity, I interpret the model as for manufacturing and set L_i to the manufacturing employment of i (World Bank).

Talent and knowhow distributions. Calibrating talent and knowhow distributions requires comparable data across countries. I use the cognitive test score data in Hanushek and Woessmann (2012a) to calibrate talent distributions. I set the distribution of the U.S. to the standard log normal. I then calibrate the distribution of other countries by matching their test score distribution statistics relative to those of the U.S.

I use the World Management Survey (Bloom et al., 2012a) to calibrate knowhow distributions. The survey provides firm-level management scores for many countries, and these scores have been shown to be strongly correlated with firm performance. In the survey, interviewers rate firms on their talent management policy and production efficiency along various dimensions. The sub-score on talent management intends to capture whether firms follow good practices for retaining and incentivizing talent, so it closely maps to the capacity of a firm in R&D, where talent plays a crucial role. I use the mean, standard deviation, and skewness of this sub-score for each country to calibrate $G_o^E(\tilde{z}^R)$.[23] I define firms' production management score as the average of their sub-scores on targeting, operation, and monitoring—all of which closely connected to being efficient at production tasks. I classify a firm as being from the high productivity distribution if its production management score is among the top 5% in the sample.[24] I then estimate the relationship between a firm's talent management score and whether it has a high production management score using the Logit model implied by equation (19). As reported in Appendix C.2, I find that $\delta_0 = -5$, $\delta_1 = 0.21$.

4.3 Parameters Determined in Equilibrium

The remaining parameters, determined jointly, include production efficiency distribution parameters $\{\underline{z}_L^P, \underline{z}_H^P, \kappa_P\}$, country-specific productivity $\{T_m | m = 1, ..., N\}$, numbers of firms from different

[22]See https://cmosurvey.org/about/

[23]Some countries are not covered by the World Management Survey. I impute their statistics based on income and the geographic regions of countries. Appendix C.1 reports additional details on the calibration of knowhow.

[24]The choice of this 5% cutoff is motivated by the importance of large firm in international business. A high cutoff allows me to better capture the activities of these firms. This cutoff corresponds to about top 12% in the U.S.

Table 3: Parameters Calibrated Externally

Symbol	Description	Value	Source
σ	elasticity of substitution between varieties	4	markup (33%)
θ	dispersion of offshore production draws	4.5	marketing expenditure/sales (8.3%)
γ	researcher share of variable profit	0.25	R&D expense/sales (4%)
δ_0	probability of high production efficiency	-5	estimated (Table C.3)
δ_1	dependence of z^P on z^R	0.21	estimated (Table C.3)
$\{\tau_{md}\|m,d=1,...,N\}$	trade costs	-	World Input Output Database
$\{G_o^E(\tilde{z}^R)\|o=1,...,N\}$	innovation efficiency dist.	-	Bloom et al. (2012a)
$\{A_i(\alpha)\|i=1,...,N\}$	talent dist.	-	Hanushek and Woessmann (2012a)
$\{L_i\|i=1,..,N\}$	labor endowment	-	World Bank & PWT

origins $\{E_o|o=1,..,N\}$, frictions to offshore production and R&D, which include bilateral coefficients $\{\overrightarrow{\beta^{P,om}}, \overrightarrow{\beta^{P,im}}, \overrightarrow{\beta^R}, \overrightarrow{\beta^{fR}}\}$, host-specific barriers $\{\phi_m^P, \phi_i^R, \phi_i^{fR}|i,m=1,..,N\}$, and the weight parameter $\{s\}$. This subsection describes the intuition on identification and the numerical algorithm used in calibration.

Firm production efficiency parameters. Given the distributions of innovation efficiency, parameters in $G_H^P(z^P)$ and $G_L^P(z^P)$ are the remaining degrees of freedom for the firm size distribution. I normalize $\underline{z}_L^P$ to 1, and pick $\underline{z}_H^P$ and κ_P jointly. κ_P governs the shape of the firm size distribution at the very top, while $\underline{z}_H^P$ has an influence on the scale of the top 5% relative to the rest of firms. I choose these parameters so that the model matches the data on the U.S. firm size distribution.

Measure of firms. The measure of firms from a country E_o, along with their innovation efficiency, determines the fraction of the world patents invented by firms from o, $\frac{\sum_d V_{od}}{\sum_{o,d} V_{od}}$. I normalize E_{US} and chose $\{E_o : o \neq \text{US}\}$ so $\frac{\sum_d V_{od}}{\sum_{o,d} V_{od}}$ in the model is aligned with its empirical counterpart.

Country-level efficiency. Given the endowment distributions, T_m captures the residual variation in country m manufacturing efficiency. I calibrate T_m so $\frac{X_m}{P_m}$ matches country m real GDP.

Geographic frictions. The remaining parameters are the geographic frictions that determine firms' allocation of R&D and production.

To infer the host-specific barrier ($\{\phi_m^P, \phi_i^R, \phi_i^{fR}|i,m=1,..,N\}$), I target the openness of countries to inward offshore activities, using the following moments: the foreign share of patents invented in a host $\frac{\sum_{o,\ o\neq i} V_{oi}}{\sum_o V_{oi}}$, the foreign share of R&D center counts $\frac{\sum_{o,\ o\neq i} R_{oi}}{\sum_o R_{oi}}$, and the foreign share of manufacturing production $\frac{\sum_{o,\ o\neq m} Y_{om}}{\sum_o Y_{om}}$. The empirical counterparts of these moments are aggregated from my firm-level data, as described in Appendix C.1.

I estimate the remaining parameters in equation (20) through indirect inference. I conduct five auxiliary regressions designed to capture various forms of frictions. Observe first from (2) that the invention of a firm in host i increases in ϕ_{oi}^R. Related, the entry cutoff $\hat{z}_{oi}^R$ increases in f_{oi}^R and decreases in ϕ_{oi}^R. If f_{oi}^R and ϕ_{oi}^R both vary strongly with proximity, so should the entry decision and the size of offshore R&D centers. Therefore, my first two auxiliary regressions, which help pin down $\overrightarrow{\beta^R}$ and $\overrightarrow{\beta^{fR}}$, take the following form:

$$y_{fh,t} = FE + \overrightarrow{\gamma}_{dist} \cdot \overrightarrow{dist}_{oh} + \epsilon_{ohf,t}.$$

$y_{fh,t}$ is the measure of R&D activity in host h of firm f from country o in period t, FE denotes firm and host fixed effects, and $\overrightarrow{dist}_{oh}$ are measures of distance between h and o (Mayer and Zignago, 2011). The first two columns of Table 4 report the results. As anticipated, the coefficient for geographic distance is strongly negative, and the indicators for proximity are positive.

The three remaining auxiliary regressions help pin down ϕ^P_{oim}. For intuition, consider a firm with *only one* R&D center. From expression (8), its production in host m specializes to

$$\log(r_{om}(\mathbf{z}^R,\mathbf{z}^P)) \propto \log\left((T_m/W^l_m)^\theta \sum_d X_d^{\frac{\theta}{\sigma-1}} P_d^\theta (W^h_d f^M_d)^{\frac{\theta+1-\sigma}{1-\sigma}} / (\tau_{md})^\theta\right) + \log\left([h_{oi}(z^R_i,z^P_i)]^\gamma (z^P_i)^\theta z^R_i\right)$$
$$+ \theta(1-s)\cdot \mathbb{1}_{(m\neq o)} \cdot (\phi^P_m + \overrightarrow{\beta^{P,om}} \cdot \overrightarrow{dist_{om}}) + \theta s \cdot \mathbb{1}_{(m\neq i)} \cdot (\phi^P_m + \overrightarrow{\beta^{P,im}} \cdot \overrightarrow{dist_{im}}), \quad (21)$$

The first two terms on the right hand side are, respectively, specific to host country m and to the firm—and hence can be controlled through fixed effects; the third and fourth terms capture how the proximity to the headquarters and to the R&D center facilitates production. Following this intuition, I use three variants of the following specification as auxiliary regressions:

$$y_{fh,t} = FE + \overrightarrow{\gamma}_{dist} \cdot \overrightarrow{dist}_{oh} + \gamma_{R\&D}\, \mathbb{I}_{RD_{fh,t}>0} + \overrightarrow{\tilde{\gamma}}_{dist} \cdot \overrightarrow{dist}_{fh,t} + \epsilon_{fh,t}.$$

The outcome variable is the affiliate sales of firm f in host h; FE is a set of fixed effects; $\overrightarrow{dist}_{oh,t}$ is the distance between h and o; $\mathbb{I}_{RD_{fh,t}>0}$ indicates whether the firm conducts R&D in host h, $\overrightarrow{dist}_{fh,t}$ is the average distance between h and all other countries where firm f has an R&D center.

In all three variants, I control for firm-period and host-period fixed effects. The first variant, reported in Column 3 of Table 4, includes only the distance to headquarters. It is most informative about $(1-s)(\overrightarrow{\beta^{P,om}})$. The second, reported in Column 4, further includes the dummy for having an R&D center in host h. The coefficient for the dummy and the change in the estimated distance coefficients compared to Column 3 captures the importance of proximity to the headquarters versus R&D. Lastly, in Column 5, I control for pair fixed effects but add the average distance to the sibling R&D centers of firm f. These coefficients help pin down $s \cdot \overrightarrow{\beta^{P,im}}$.[25]

To implement this indirect inference, I simulate a sample of 50,000 firms from the model, using country size as the sample weight. I conduct the auxiliary regressions on the resulting sample, choosing $\{\overrightarrow{\beta^{P,om}}, \overrightarrow{\beta^{P,im}}, \overrightarrow{\beta^{R}}, \overrightarrow{\beta^{cR}}\}$ and s to minimize the L^2 norm between the coefficients reported in Table 4 and those from the same regressions using the simulated data. With 22 target coefficients and 17 parameters, the model is over-identified. In constructing the objective function, I weight regression coefficients using the inverse of their empirical standard errors, acknowledging that these coefficients are not estimated with the same precision.

Numerical implementation. I determine the parameters in this subsection using a nested fixed point algorithm. In the outermost layer, I choose $\underline{z}^P_H$ and κ^P to match the moments on firm size. In the middle loop, I search over the space of $\{s, \overrightarrow{\beta^{P,om}}, \overrightarrow{\beta^{P,im}}, \overrightarrow{\beta^{R}}, \overrightarrow{\beta^{fR}}\}$ to minimize difference in regression coefficients based on simulations. In the innermost loop, I solve for the competitive

[25]Parameter s can be separately identified from $\overrightarrow{\beta^{P,im}}$ and $\overrightarrow{\beta^{P,om}}$ because s also enters affiliate production through ϕ^P_m, which is pined down by the overall foreign production share in m.

Table 4: Auxiliary Regressions for Inferring Geographic Parameters

	Headquarters Effect			Colocation	
	(1)	(2)	(3)	(4)	(5)
Dependent var.	R&D indicator	log (R&D)	log(sales)	log(sales)	log(sales)
log(dist)$_{oh}$	-0.002**	-0.129***	-0.282***	-0.253***	
	(0.001)	(0.034)	(0.028)	(0.020)	
Common language$_{oh}$	0.020***	0.258***	0.162**	0.094**	
	(0.004)	(0.072)	(0.067)	(0.037)	
Contiguity$_{oh}$	0.002	0.106	0.185***	0.174***	
	(0.002)	(0.072)	(0.064)	(0.036)	
Colonial tie$_{oh}$	0.002	0.029	0.153*	0.129***	
	(0.004)	(0.067)	(0.079)	(0.037)	
R&D center indicator				1.198***	1.042***
				(0.026)	(0.026)
log(dist$_{fh,t}$)					-0.024
					(0.025)
Common language$_{fh,t}$					0.220***
					(0.051)
Contiguity$_{fh,t}$					0.143***
					(0.049)
Colonial tie$_{fh,t}$					0.090**
					(0.046)
Observations	7295102	45364	103131	103131	119503
R^2	0.124	0.336	0.420	0.445	0.496

Note: All columns control for firm-period, host-industry, and host-period fixed effects; in addition, the last two columns also control for home-host fixed effects. These regressions also appear in Appendix A.4 with robustness results. Standard errors (in parenthesis) are clustered by country pair in the first three columns and by firm in the last two columns. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

equilibrium, while choosing $\{T_m|m = 1, ..., N\}$, $\{E_o|o = 1, .., N\}$, and$\{\phi_m^P, \phi_i^R, \phi_i^{fR}|i, m = 1, .., N\}$ to match their respective targets described above.

Parameter values and model fit. Table 5 summarizes the results from this procedure. Panel A is the parameters determined in the outermost loop: $\underline{z}_H^P = 2$ and $\kappa^P = 6.15$. The model matches closely the three moments of the U.S. firm size distribution. Panel B is the country-specific parameters that are matched perfectly by design in the innermost layer. The target values of the moments are reported in Appendix Table C.1.

Panel C of Table 5 reports the coefficients governing the costs of offshore R&D and production. As anticipated, geographic barriers, either natural or man-made, tend to deter both offshore R&D and offshore production. I also find that $s = 0.82$, meaning that proximity to the R&D team is more important than proximity to the headquarters. This finding reflects the strong colocation pattern seen in the data and implies a highly localized effect of affiliate R&D. As shown in appendix Table C.4, with these parameters the model fits the regression coefficients well.

4.4 Validation using Non-targeted Moments

I evaluate the fit of the model on non-targeted moments in Table 6.

Employment and R&D concentration. The upper panel reports additional statistics on firm size. In the data, 90% of firms have fewer than 10 employees and 47% of employment are in firms with more than 500 employees. The model matches the former well and over predicts the latter. In 2014, about 79% of the business enterprise R&D in the U.S. is conducted by parent firms of U.S. MNCs. This share is slightly lower in the model.

The multinational managerial advantage. In the model, firm knowhow, disciplined using

Table 5: Parameters Calibrated in Equilibrium

Parameter and value	Description	Moment	Model	Data
A. Firm size dist. parameters				
$z_L^P = 1$ (normalized)		% of firms with emp.$\leq$100	0.99	0.99
$z_H^P = 2$	Firm z^P draws	% of firms with emp. $\leq$20	0.94	0.95
$\kappa^P = 6.13$		Power law coefficient of firm size dist.	1.03	1.05
B. Country-specific parameters and fixed effects				
$\{T_m \| m = 1, ..., N\}$	country-specific man. TFP	$\{\frac{X_m}{P_m}\}$	-	
$\{E_o \| o = 1, .., N\}$	measure of domestic firms	$\{\frac{\sum_i V_{oi}}{\sum_{o,i} V_{oi}}\}$	-	Columns 1-5 of Table C.1
$\{\phi_m^P \| m = 1, .., N\}$	host effect in production	$\{\frac{\sum_{o,\ o\neq m} Y_{om}}{\sum_o Y_{om}}\}$	-	
$\{\phi_i^R \| i = 1, .., N\}$	host effect in R&D	$\{\frac{\sum_{o,\ o\neq i} V_{oi}}{\sum_o V_{oi}}\}$	-	
$\{\phi_i^{fR} \| i = 1, .., N\}$	host effect in R&D overhead	$\{\frac{\sum_{o,\ o\neq i} R_{oi}}{\sum_o R_{oi}}\}$	-	
C. Bilateral Geographic Coefficients				
s=0.82	$\phi_{oim}^P = (\phi_{im}^P)^s (\phi_{om}^P)^{1-s}$			
distance **lang** **border** **colony**				
-0.066 0.010 0.043 0.026	$\overrightarrow{\beta^{P,im}}$	reduced-form estimates on colocation and headquarter effects	Table C.4 Panel B	Table 4
-0.025 0.072 0.034 0.021	$\overrightarrow{\beta^{P,om}}$			
-0.069 0.13 0.038 0.051	$\overrightarrow{\beta^{R}}$			
0.15 -0.0077 -0.053 -0.0063	$\overrightarrow{\beta^{fR}}$			

management scores, is the main source of firm heterogeneity. Self-selection by knowhow into offshore R&D implies that foreign affiliates tend to have higher management scores than indigenous firms and that this advantage is larger in low-income host countries populated with poorly managed firms. To validate these implications, I calculate the foreign affiliate managerial advantage for each country, defined as the percentage difference between the average innovation efficiency of foreign affiliates and that of indigenous firms, and compare this measure to their empirical counterparts, constructed using the World Management Survey (Bloom et al., 2014). As the middle panel of Table 6 shows, the predicted average foreign affiliate management advantage and its cross-country variations are both similar to those in the data. In addition, both the model and the data show a negative correlation between this measure and host income.

Offshore R&D entry. In the lower panel of Table 6 are the shares of firms with R&D centers in different numbers of countries. The model fits the data reasonably well except for the share of firms entering more than 6 countries: with all firms from a country facing the same offshoring entry costs, the most efficient firms in the model tend to enter more countries than in the data.

Bilateral offshoring activities. The calibration matches the overall inward offshore R&D and production of each host by design, but when it comes to *bilateral* offshore production and R&D, the only information being used is the regression coefficients identified from *within-firm* variations. I assess whether the model can match bilateral shares. I define bilateral shares as R&D/production from a foreign country over a host's own R&D/production, which assures that the fit is not driven by the overall openness of a country. Figures 5a and 5b show that for both offshore R&D and production, the model fits the data well.

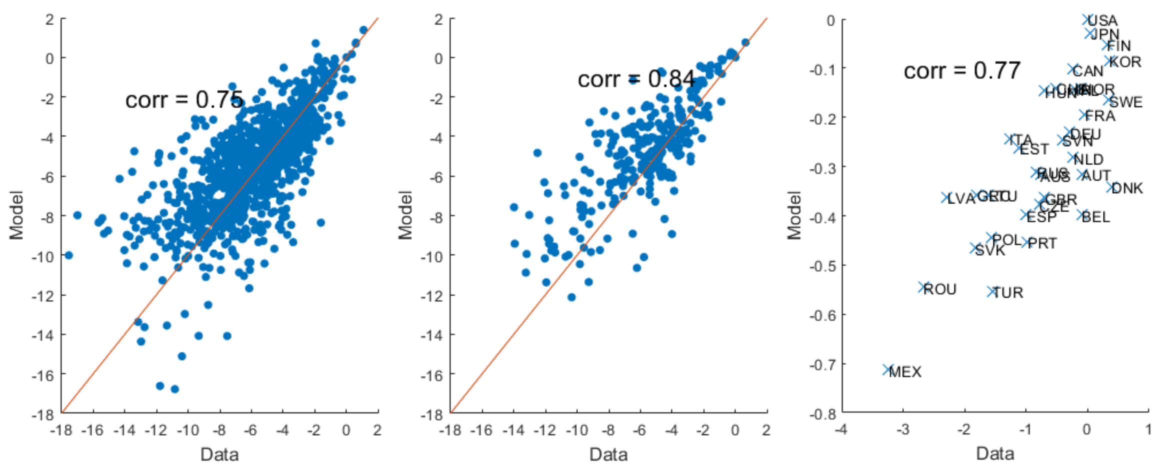
Occupation shares. By matching R&D by firms' headquarters country and the real income

Table 6: Fit of Non-targeted Moments

Additional moments on firm size in U.S.	**Model**	**Data**
Fraction of firms with emp. ≤ 10	0.91	0.90
Share of emp. in firms with emp. > 500	0.61	0.47
Share of R&D by parents of MNCs	0.77	0.79
The efficiency advantage of foreign affiliates		
Foreign affiliate advantage	0.22	0.15
Coefficient of variation across countries	1.18	1.16
Correlation with host log GDP per capita	-0.08	-0.25
Entry into Offshore R&D		
% of firms with R&D centers in 1 country	93.3	95.3
2 countries	2.2	2.7
3 countries	0.6	0.6
4 countries	0.6	0.3
5 countries	0.3	0.3
>= 6 countries	3.0	0.7

Figure 5: The Fit of the Model on Aggregate Moments

(a) Offshore Production (b) Offshore R&D (c) Share of High-Skill Workers

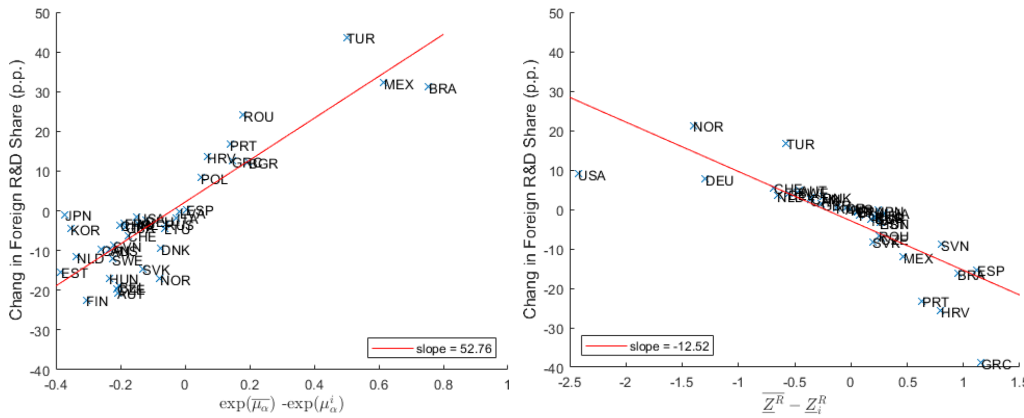


Notes: The left and middle panels show the fit of the model in log bilateral production shares ($\log(\frac{Y_{om}}{Y_{mm}})$) and log bilateral offshore R&D shares ($\log(\frac{V_{oi}}{V_{ii}})$), respectively. The right panel shows the fit of the model in log high-skill occupation shares. The vertical axis is the log of countries' high-skill share in the model ($(1 - A_i(\hat{a}_i))$) relative to that of the U.S.; the horizontal axis is the log of countries' share of researchers in industrial employment relative to that in the U.S. obtained from the OECD.

by country, my calibration indirectly disciplines the shares of national income from high-skill occupations and other sources. Whether the implied sources of income translate into a reasonable occupation distribution of workers boils down to if the log normal distribution, parameterized to match cognitive test scores, is a good approximation to the reality. As a validation of these assumptions, Figure 5c plots the share of workers sorting into high-skill occupations against the share of researchers in industrial employment from the OECD. The range of variation in the model is smaller than that in the data, likely because the definition of skill in the data is narrower. Despite this difference, the correlation between the two variables is quite high.

Figure 6: The Role of Endowment Distributions

(a) Talent distribution (b) Firm Distribution



Notes: The vertical axis is the change (in p.p.) in the share of R&D by foreign firms. The horizontal axis in the left panel is $\exp(\overline{\mu}^i_\alpha) - \exp(\mu^i_\alpha)$, in which μ^i_α is the talent parameter of country i in the baseline economy (with $\exp(\mu^i_\alpha)$ being the median of the talent distribution), and $\overline{\mu_\alpha} \equiv \frac{\sum_i \mu^i_\alpha}{N}$ is the average talent parameter in the world. The horizontal axis in the right panel is $\overline{\underline{Z}^R} - \underline{Z}^R_i$, in which $\underline{Z}^R_i$ is the lower support of the firm knowhow distribution in country i and $\overline{\underline{Z}^R} \equiv \frac{\sum_i \underline{Z}^R_i}{N}$ is the average lower support in the world.

5 Counterfactuals

In this section, I conduct counterfactual experiments to shed light on the factors that shape offshore R&D and the welfare implications of offshore R&D.

5.1 How Host Endowment and Geography Shape Offshore R&D

In the model, a host country's access to downstream producers and—through them—consumers, and its relative abundance in talent play a central role in shaping offshore R&D. I assess the quantitative relevance of these two forces by varying countries' distributions of talent and knowhow, and their access to foreign producers and customers.

The role of endowment distributions. I focus first on the role of endowment distributions. For each host, I separately set the location parameters for its talent and knowhow distributions, μ^i_α and $\underline{Z}^R_i$, to their respective mean values among the sample countries, $\overline{\mu_\alpha}$ and $\overline{\underline{Z}^R}$. To isolate the impacts of changes in other countries, I change parameters for one country at a time, keeping parameters of all other countries at the calibrated values.

Figures 6a and 6b, respectively, plot the change in inward offshore R&D for countries after their talent quality parameter μ^i_α and knowhow distribution parameter $\underline{Z}^R_i$ is changed to the world average. The figures show that as countries' talent distribution improves and as their knowhow distribution deteriorate, their inward offshore R&D increases, as implied by the first two parts of Proposition 2. Both effects are sizable. According to the fitted lines, an increase of 0.4 in talent distribution parameter, or a quarter of the sample range in this parameter, increases inward offshore R&D by 20 p.p. A decrease in the country's knowhow parameter by 1, also approximately a quarter of the sample range, increases inward offshore R&D by 12.5 p.p.

Table 7: Market Access and Offshore R&D for Select Countries

Emerging	Benchmark (1)	Eliminate Access to: Consumer (2)	Eliminate Access to: Producer (3)	Eliminate Access to: Both (4)	Developed	Benchmark (1)	Eliminate Access to: Consumer (2)	Eliminate Access to: Producer (3)	Eliminate Access to: Both (4)
BRA	57.55	67.66	1.74	48.32	BEL	58.85	78.72	9.45	2.19
CHN	42.22	51.45	0.71	33.92	FRA	26.73	30.47	6.57	16.93
POL	14.68	50.44	4.40	2.44	JPN	3.04	3.16	4.20	1.93
RUS	11.54	25.34	2.91	1.31	USA	16.31	16.45	6.37	11.41
mean (all)	34.86	50.74	6.69	15.96					

Notes: The numbers reported in this table are the share of domestic R&D expenditures incurred by affiliates of foreign companies in each country. All numbers are in percent. 'Benchmark' is for the baseline equilibrium; 'Consumer' is for when the access of a host to foreign consumers through exporting is shut down; 'Producer' is for when the access of a host to foreign producers through offshore production is shut down; 'Both' combines changes in 'Consumer' and 'Producer' for each country. The last row reports the mean values among all countries.

These findings show that endowment distributions are a first-order determinant for offshore R&D in individual hosts. To assess the extent to which endowment distributions can explain the aggregate offshore R&D, I 'squeeze' the incentive for offshore R&D by giving all countries the best knowhow distribution (setting $\underline{Z}_i^R$ to that of the U.S.) and the worst talent distribution (setting μ_o^i to that Brazil). The former change increases the competition faced by foreign firms in all hosts from local firms, whereas the latter change reduces the attractiveness of host talents. I find that if all countries had the best knowhow, then the share of global R&D done in offshore locations decreases from 29.5% in the baseline model to 22.7%; if all countries had the worst talent, then the share would be 3.2%. If both changes happen simultaneously, then global offshore R&D would decrease to a mere 1% of total R&D. Therefore, the measured variations in endowment differences can account for a substantial part of world offshore R&D.

The role of host country market access. I now examine how equilibrium offshore R&D is affected by host countries' access to foreign consumers through exporting and their access to foreign manufacturers through offshore production. In the first experiment, I increase the export cost of the host country (τ_{md}) to infinity, which cuts off its direct access to foreign consumers. While this makes the country a less desirable location for offshore R&D in partial equilibrium, the general equilibrium effect described in Proposition 1 pushes it to specialize in innovation, drawing in more R&D centers. Quantitatively, the general equilibrium effect dominates. Reported in Column 2 of Table 7 are the shares of R&D by foreign firms for a set of selected emerging (left panel) and developed (right panel) countries in this scenario. The inward offshore R&D increases in all these hosts when they can no longer export.

In the second experiment, I increase the cost of offshore production from a host country to infinity (by setting $\phi_{oim}^P = 0, m \neq i$), so inventions in i, by both domestic and foreign firms, can be produced only locally. Column 3 shows that this change decreases the offshore R&D in most countries. As in the previous experiment, in partial equilibrium, not being able to offshore production makes a host less attrative for R&D. However, here the general equilibrium effect tend to reinforce the partial equilibrium effect: when the option of offshore production is eliminated, R&D centers in the host have to produce locally to serve both foreign and domestic customers, which increases wages, making the country even less attractive for R&D.

Column 4 reports the shares of offshore R&D when both types of market access are eliminated. In this case, inventions in a host country can only be produced locally for local consumers. To understand the results, we can view this scenario as the result of eliminating export opportunities from the equilibrium without MP (Column 3). As discussed in the description of the results in Column 2, eliminating export opportunities leads to opposing partial and general equilibrium effects. Unlike in that case, however, here the general equilibrium effect is weaker. The intuition is that the general equilibrium effect operates through countries' specialization in innovation/production, and this mechanism is not feasible when MP is shut down. As a result, aside from countries with a big domestic market, such as China, Brazil and the United States, many countries see lower inward offshore R&D compared to Column 3. Compared to the values in the baseline equilibrium, the average offshore R&D of the sample countries deceases by more than half to 16%, so the net effect of the two types of access on offshore R&D is positive.

5.2 Offshore R&D and the Gains from Openness

I now turn to the implications of offshore R&D for welfare.

The gains from offshore R&D. I first calculate countries' gains from offshore R&D, defined as the increase in the aggregate real income of a country ($\frac{X_d}{P_d}$) as the economy moves from the equilibrium where offshore R&D is prohibitively costly ($\phi^R_{oi} = 0, i \neq o$) to the baseline equilibrium. The first column in Table 8 reports the results. The simple average across all countries is 3.47%. There is, however, important heterogeneity. While all countries are better off with offshore R&D, advanced countries (lower panel) benefit more than emerging economies (upper panel).

This heterogeneity occurs because advanced countries are the main sources of world knowhow and generally more open to inward offshore R&D. Consequently, they benefit more from offshore R&D both through a higher innovation rent enabled by offshore R&D and through an improvement in R&D efficiency due to foreign entrants (larger $\frac{X_d}{Y_d}$ and smaller $(\frac{\sum_m X_{ddmd}}{\sum_{o,m} X_{odmd}})$ in equation 15). The combined impact of these two channels can be approximated by the share of total innovation income generated through offshore R&D, which includes the profit of domestic firms from overseas R&D and the income of domestic researchers working at foreign affiliates. Figure 7a shows that this measure explains most of the variation in the gains from offshore R&D.

To put the numbers in perspective, I reported in Columns 2-3 of the Table 8 countries' gains from trade and MP. As expected, small countries close to major markets (e.g., Belgium) gain more from both channels, whereas large and remote countries (e.g., Brazil) gain less. The average gains from trade and MP are 3.3% and 8.4%. The gains from offshore R&D are smaller than that from MP, but around the same magnitude as the gains from trade.

Interaction among the three forms of globalization. In addition to bringing direct welfare gains, offshore R&D also interacts with trade and MP. We can understand the impact of such interaction for welfare by comparing the sum of the gains from these individual channels to the gains from openness, reported in Column 4. If the sum is larger, it means the benefit of further openness is greater once a country is already open in other dimensions, so the three channels are

Table 8: Offshore R&D and the Gains from Openness

Country	Baseline model: Off. R&D (1)	Trade (2)	MP (3)	Openness (4)	Alternative models: No Off. R&D Openness (5)	$s=0$ (or $\phi^P_{oil}=\phi^P_{ol}$) Off. R&D (6)	Openness (7)
BRA	0.68	0.71	0.76	2.17	1.56	6.90	10.30
CHN	0.88	0.52	1.12	2.62	1.84	1.86	5.30
POL	1.31	2.37	5.41	9.56	9.46	8.22	21.03
RUS	0.72	1.23	3.54	5.71	5.74	5.08	12.72
BEL	5.02	5.60	20.93	33.73	27.57	3.97	39.70
FRA	2.26	3.47	9.51	14.71	13.75	3.67	20.68
JPN	1.92	2.10	4.77	7.32	5.92	3.48	13.91
USA	9.18	5.16	9.57	22.24	12.58	4.64	26.49
Mean (all)	3.47	3.31	8.35	15.58	12.15	8.22	26.21
Std (all)	4.66	1.96	10.70	16.27	12.51	5.02	14.84

Notes: All numbers are in percent. Columns 1 to 4 reports the gains from offshore R&D, trade, offshore production, and openness, respectively. Column 5 reports the gains from openness in a restricted model without offshore R&D, calibrated to match the same patterns of trade and offshore production as in the baseline equilibrium. Columns 6 and 7 report the gains from offshore R&D and openness for a re-calibrated model that assumes that $s = 0$.

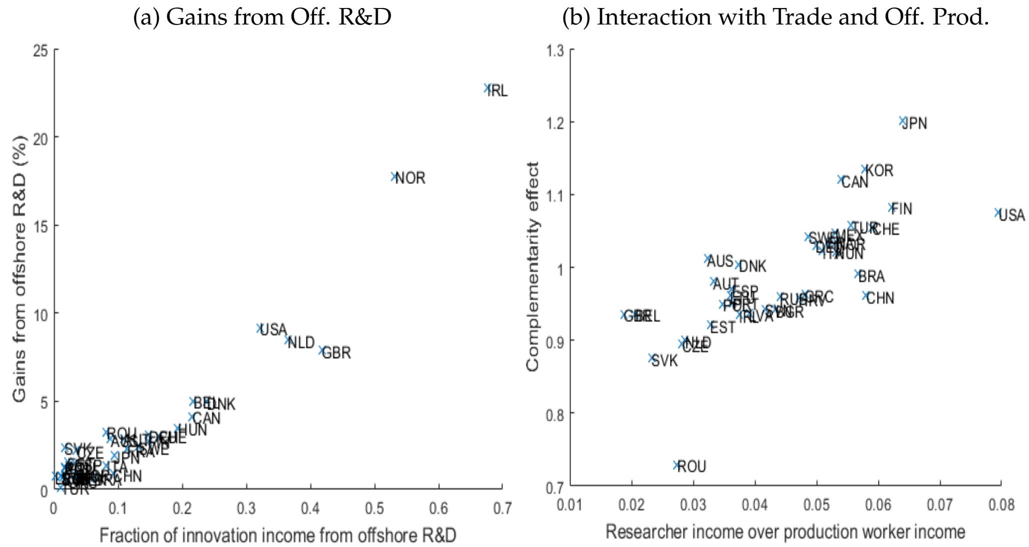
complements; conversely, the three channels are substitutes.[26] I plot the ratio between the sum of the gains from individual channels and the overall gains from openness in the vertical axis of Figure 7b. The ratio ranges from 0.7 to 1.2, suggesting the interaction with offshore R&D can change the gains from trade and MP in either direction by up to a quarter.

Intuition from Proposition 3 is helpful in understanding this result. With efficient firms mobilizing innovation knowhow globally, offshore R&D increases R&D efficiency everywhere. This reinforces the comparative advantage of countries already specializing in innovation but weakens the comparative advantage of those specializing in production. As such specialization is an important mechanism for the gains from trade and MP, offshore R&D increases the gains from trade and MP for the former group of countries and has the opposite effect for the latter. I measure the specialization of a country using the income ratio between researchers and production workers in the equilibrium obtained by shutting down offshore R&D from the baseline economy. The horizontal axis of Figure 7b orders countries by this measure. It shows that specialization in the absence of offshore R&D explains most of the variation in the degree of complementarity/substitution of the three channels for countries.

Impact on the gains from openness. Overall, how does offshore R&D change the inferred gains from openness? To answer this question, I calculate the gains from openness in a restricted model without offshore R&D, calibrated to match the same trade and MP data. As reported in Column 5 of Table 8, this alternative model implies an average gains from openness of 12.2%. Comparing Columns 4 and 5 shows that offshore R&D amplifies the average gains from openness by a factor of 1.3 (15.6/12.2). The amplification differs significantly across countries. Advanced countries making substantial profit from offshore R&D tend to receive bigger increases in inferred

[26]Note that the gains from individual channels are calculated from the calibrated equilibrium with the other two channels both present. If the sum of individual channels is larger than the gains from openness, it means for at least one of the channels, the effect of integration is larger when the other two channels are already present.

Figure 7: The Gains from Offshore R&D and Interaction with Trade and Offshore Production



Notes: The left panel shows that the gains from offshore R&D (vertical axis) are higher in countries where offshore R&D account for a higher share of the innovation rent. The innovation rent is the sum of researcher income and profit in a country. Among it, the fraction accounted by offshore R&D is the profit of domestic firms doing R&D abroad plus the income of domestic researchers working in foreign R&D centers. In the right panel, the vertical axis is the ratio between the sum of individual gains and the gains from openness. The horizontal axis is the ratio between researcher income and production income.

gains. For example, the inferred gains from openness of the U.S. almost double when offshore R&D is incorporated. For emerging countries, the amplification is generally smaller and could be slightly negative (e.g., Russia). The uneven changes between the baseline and restricted models further underscore the importance of incorporating offshore R&D—its omission not only underestimates the gains from openness but also biases the comparison of the gains across countries.

The role of geographic frictions. In the model, the cost of MP is specified as a combination of distance to headquarters and distance to R&D centers. My estimates suggest that $s = 0.82$, which implies highly localized effect of affiliate R&D. Now I show that the value of s, which I discipline carefully using firm-level data, is crucial for correctly inferring the welfare gains.

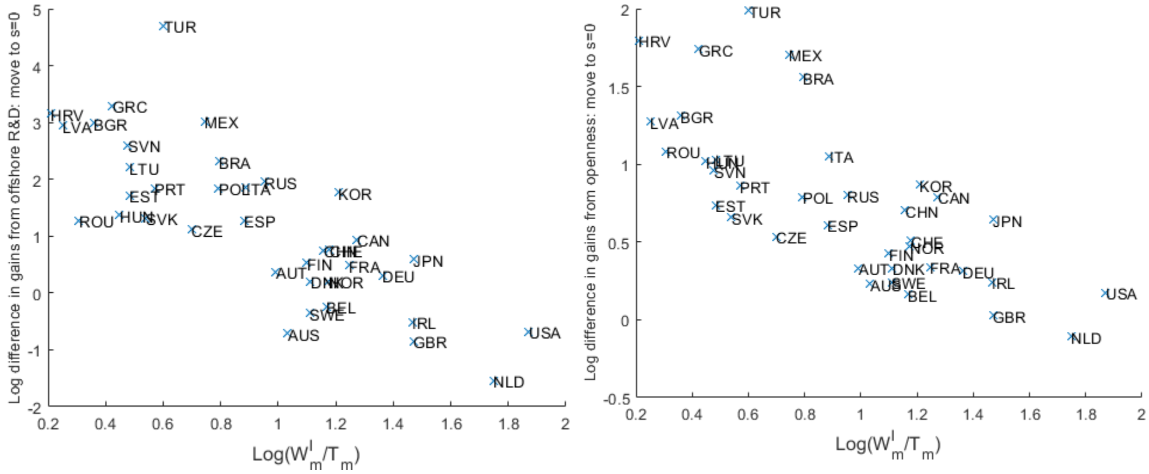
To this end, I calculate the gains from offshore R&D and openness in a re-calibrated model with $s = 0$, which implies much lower frictions for products invented in offshore locations to be produced at headquarters.[27] The last two columns of Table 8 report the gains from offshore R&D and openness in this re-calibrated model. The average gains from offshore R&D increase to 8.2% from the benchmark value of 3.5%, but the increases are concentrated in emerging countries. In fact, the gains from offshore R&D for the U.S. shrink by almost half.

The difference occurs because the baseline model infers R&D as mostly for production in host countries, which competes primarily with local firms, whereas the alternative model infers it as mostly for headquarters production, which competes with other firms from the home country. Because developing countries with lower production costs have a higher local production share

[27] In this calibration, I choose parameters in Panel B of Table 5 to match the corresponding targets, keeping the parameters in Panel C (other than s) the same as in the baseline equilibrium. This alternative parameterization implies that 70% of the profit from affiliate R&D is through production at the headquarters. This is much higher than in the baseline model (4%) and inconsistent with the finding of Bilir and Morales (2020).

Figure 8: Geographic Frictions and the Gains from R&D and Openness

(a) Setting $s = 0$ redistributes the gains from off. R&D (b) Setting $s = 0$ amplifies the gains from openness



Notes: The horizontal axis in both panels is log of effective production cost in a country. The vertical axis is log of the ratio between the gains in the alternative model with $s = 0$ and the gains in the baseline model. The left panel focuses on the gains from offshore R&D; the right panel focuses on the gains from openness.

of inward offshore R&D, moving to the alternative model with $s = 0$ leads to a more significant reduction in the competition faced by their domestic firms. This, in turn, results in a larger increase in the inferred gains from offshore R&D. The opposite is true for developed countries. Figure 8a plots the log change in gains from offshore R&D from the baseline to the alternative model with $s = 0$ and shows that indeed it is the countries with higher effective production costs that see the inferred gains from offshore R&D decreased.

Figure 8b shows that the negative slope continues to hold for the changes in the gains from openness from the baseline to this alternative model. Different from the gains from offshore R&D, however, the change are positive for almost all countries. This across-the-board increase in the inferred gains occurs because the alternative model implies a higher degree of integration through offshore production. Recall that in calibration I match by country the share of domestic production by foreign firms ($\frac{\sum_{o,o\neq m} Y_{om}}{\sum_o Y_{om}}$), an important part of which is for the varieties developed locally by foreign R&D centers. The alternative model, in which more offshore R&D is for production at the headquarters, matches the same $\frac{\sum_{o,o\neq m} Y_{om}}{\sum_o Y_{om}}$ by allowing for more MP, implicitly increasing the openness of the economy and hence generating higher gains for all.

Summary. Taking stock, the exercises in this section demonstrate that offshore R&D represents a quantitatively important channel through which countries benefit from globalization. It is a substitute for trade and MP for emerging countries but a complement for advanced countries. Furthermore, the nature of offshore R&D—whether the inventions are devoted to local production or elsewhere—matters for the gains from offshore R&D and openness, which underscores the value of constructing the firm-level dataset and using it to discipline the model.

6 Conclusion

Talented researchers and efficient firms are both necessary inputs to the development of new products, but they are distributed unevenly across countries. In a world separated by geographic frictions, MNCs organize their R&D and production to overcome this mismatch, bringing welfare gains to participants from different parts of the economy.

This paper develops a general equilibrium model of firms' global R&D and production decisions. Disciplining the model using micro and macro data, I find that offshore R&D brings about 3.5% welfare gains and amplifies the gains from openness by a factor of 1.3. These effects are especially large for developed countries, which derive a significant fraction of the value of their knowhow through overseas R&D. Moreover, because of its interconnection with integration via trade and MP through both within-firm linkages and general equilibrium effects, understanding offshore R&D matters for these more familiar forms of globalization as well.

This paper abstracts from some aspects of the reality that might prove useful for measuring and theorizing about offshore R&D. For example, the model incorporates different tasks in bringing a product to consumers but has overlooked the role of sectors. Incorporating sectors can shed light on the role of sectoral comparative advantage and its interaction with relative talent abundance. Second, I have focused on offshore production within the boundary of firms. Enriching the model to accommodate outsourcing through arms' length transactions will paint a more complete picture of how offshore R&D affects country specialization and income.

Data Availability Statement

The replication package for this paper can be accessed at 10.5281/zenodo.10730105.

This paper has two components. The first one is an empirical analysis using firm-level data. The dataset builds on two proprietary databases: PATSTAT Global and ORBIS. Both databases can be accessed through the vendors as described in the replication package. The rest of the datasets used in the empirical analysis are publicly accessible and are included in the replication package.

The second component of the paper is a simulation analysis. This analysis uses aggregate moments and reduced-form estimates from the firm-level data and publicly accessible data to calibrate key parameters of the model and to conduct counterfactual experiments. All codes and data that are necessary to the simulation results are included in the replication package.

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