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Knowledge Transfer Abroad: The Role of U.S. Inventors within Global R&D Networks
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ABSTRACT

The location of US multinational foreign R&D has shifted significantly to include emerging markets in addition to traditional Western R&D hubs, resulting in two challenges for multinationals: (1) how to transfer knowledge across geographic distances, and (2) how to facilitate learning when local knowledge sources in given technological areas are inadequate. This paper argues that to overcome these challenges, multinationals utilize home country inventors on foreign affiliate inventor teams – and in particular on teams in locations with insufficiently specialized local knowledge stocks – to facilitate knowledge transfer. Empirical analysis of a comprehensive dataset of US multinational R&D and patenting activity provides robust support for this argument. The findings have important implications for understanding how countries can gain expertise in technical areas and how poor countries can escape the knowledge trap, and they provide insight into management of increasingly dispersed multinational global R&D networks, particularly in locations with relatively unspecialized local inventors.

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1. Introduction

Over the past few decades, the distribution of multinational R&D investment across countries and industries has undergone a dramatic shift. Foreign R&D has grown dramatically; between 1989 and 2013, US multinational foreign R&D expenditure grew seven-fold (Bureau of Economic Analysis). Furthermore, the location of foreign R&D has shifted; traditionally, overseas R&D was concentrated in developed, industrialized nations. Over the last decade, there has been not only an increase in the number of R&D destinations, but also especially fast growth in less developed emerging markets like China and India, as illustrated in Figure 1.

Countries have different national innovative capacities (Furman, Porter, and Stern 2002; Chung and Yeaple 2008), with relatively few countries at the technological frontier. Because knowledge spillovers are geographically constrained (Jaffe, Trajtenberg, and Henderson 1993) in emerging markets the degree of access to existing stocks of knowledge – and particularly knowledge at the technological frontier – is limited. While the changing foreign R&D landscape and what it means for multinational firm strategy has not gone wholly unnoticed (Alcacer and Zhao 2012; Zhao 2006; Macher and Mowery 2008), the shifting distribution of multinational R&D investment is inconsistent with the dominant view in the literature that the purpose of multinational R&D investment is to leverage location-specific knowledge (Chung and Alcácer 2002; Berry 2006; Zander 1999; Berry and Kaul 2015). The growing body of strategy research on knowledge-seeking assumes that firm incentives are to conduct R&D in countries at the technological frontier[1], but firms increasingly are also conducting R&D in countries far from the technological frontier.

The literature's understanding of the motivation behind and the management of R&D in emerging markets is underdeveloped, but we know that at least two of the incentives for conducting R&D in these countries include lower costs (e.g. Hegde and Hicks 2008; Athukorala and Kohpaiboon 2010) and access to local markets (e.g. Vernon 1966; Mansfield et al 1979). A comparison of international engineer salaries

[1] Although the environmental context, like expropriation (Alcacer and Zhao 2012) and the technological sophistication and political hazards of the country (Henisz and Macher 2004) also matter.

further underscores one of these motives for conducting R&D in emerging economies; researchers in these countries cost a fraction of those in the United States. These low costs present an opportunity for US multinationals, but to take this opportunity, firms must find a mechanism for transferring competence in specialized technical areas to local inventors who have limited access to existing stocks of knowledge. The literature thus far has largely failed to address this and other management challenges faced by multinationals conducting R&D in emerging markets[2].

This paper seeks to fill this gap in the literature and to contribute to our understanding of MNC management of R&D in emerging markets. In particular, we examine the following paradox: R&D is a knowledge-intensive activity and requires specialized, highly-trained labor, but local knowledge sources in emerging markets are often far from the technological frontier in key technical areas. How can multinationals overcome the lack of local knowledge stocks in key technical areas in poor countries and still effectively conduct R&D?

In this paper, we argue that in order to overcome (1) the challenges in transferring knowledge across geographic distances and (2) the lack of local knowledge sources in key technical areas in newer R&D destinations, multinationals utilize home country inventors on foreign affiliate inventor teams to facilitate knowledge transfer. We develop a simple model of knowledge transfer within foreign affiliate research streams that shows how we might observe this mechanism: through the changing composition of home country inventors on foreign affiliate inventor teams. We would expect that as local teams learn from home country inventors, the need for US inventors on foreign affiliate inventor teams would also decline as the delta in local versus home country knowledge shrinks.

We find empirical support for this theory, utilizing comprehensive data on the foreign R&D activity and patenting behavior for the universe of US multinationals from the Bureau of Economic Analysis (BEA) and comprehensive patent data for the US from the US Patent and Trademark Office (USPTO). We

[2] With the exception of (Alcacer and Zhao 2012; Zhao 2006)

document (1) that US inventors are more likely to be on a foreign affiliate research team in locations with lower knowledge stocks, (2) that there is a decline in the propensity to have US inventors on foreign affiliate inventor teams over the course of a new research stream, and (3) that the decline is more pronounced in locations with lower knowledge stocks. These results are consistent with the theory that multinationals utilize home country inventors on foreign affiliate inventor teams as a knowledge and competency transfer mechanism, particularly in countries not at the technological frontier.

Our paper sheds some light on how multinationals can manage and integrate increasingly dispersed global R&D networks, and how they are able to conduct R&D in locations that may have relatively unspecialized local inventors. We also provide some evidence that current theories of the knowledge-sourcing motivation behind the globalization of R&D may be incomplete; R&D is occurring in locations with relatively low knowledge stocks. Our findings have important implications for policymakers; we illustrate how countries can gain expertise in certain technical areas, and we describe an additional means by which multinationals might help poor countries escape the knowledge trap (Jones 2014): by providing a mechanism through which local inventors can become specialized in a technical area.

2. Theoretical Framework

2.1 The Changing Multinational Foreign R&D Landscape

Despite the global reach of MNC R&D, there is general consensus that there is no global pool of technology (Keller 2004) and that knowledge spillovers are geographically localized and do not pass easily across national borders (Jaffe, Trajtenberg, and Henderson 1993; Audretsch and Feldman 1996; MacGarvie 2005). This means that countries will differ in their knowledge profiles due to variations in location-specific factors including but not limited to previous innovations, education systems and human capital, location-specific technology development incentives, and government agencies (Chung and Yeaple 2008; Fuchs and Kirchain 2010; Furman, Porter, and Stern 2002). It also means that firms and inventors who come from countries that are leaders in technological innovation in a specific technical area will have access to a higher cumulative stock of technological knowledge in that technical area.

The idea that some countries contain higher cumulative specialized knowledge stocks than others has led to a literature that argues that multinationals have increased the number of locations in which they conduct R&D in order to gain a competitive advantage from leveraging location-specific technology, resources, and capabilities from different R&D divisions around the globe (Alcácer 2006; Chung and Alcácer 2002; Alcácer and Chung 2007; Berry 2014; Zander 1999; Berry and Kaul 2015). The knowledge-seeking motivation for foreign R&D has been well-established for firms conducting R&D in traditional R&D hubs known for specialized capabilities, like Germany and Japan. However, it does not explain the expansion of R&D networks beyond these traditional R&D hubs. Figure 2 shows the rise in importance of "non-traditional Hubs"[3] for U.S. MNCs, while Figure 3 shows that the expansion beyond traditional R&D hubs is not limited to developed countries; China, India, and other developing economies[4] have become important R&D destinations as well[5]. The rising importance of foreign R&D in these locations also suggests that the view that multinationals move R&D overseas to access technological expertise is applicable only for foreign R&D in some locations and needs to be expanded to include motivations for conducting R&D in emerging economies.

There is also surprisingly little work in the literature on how the limited knowledge access of innovators in poor countries could affect MNC strategies in those locations. Since technology differs across locations, the cumulative knowledge access of innovators in a poor country will be much more limited than the knowledge access of innovators in a wealthy one, which means that emerging economies such as India and China are still some distance from the technological frontier and have smaller knowledge stocks than traditional R&D centers in Europe and Japan. This paper will show this disparity in knowledge

[3] Composed of the UK, Germany, Japan, France, and Canada (These five countries comprised 74% of foreign R&D in 1989).
[4] Developing countries are defined using the IMF definition in the World Economic Outlook.
[5] Our interviews in India, Israel, and China, conducted in 2015 and 2016, confirm the view that the R&D labs in non-traditional hubs play increasingly important roles in MNC global R&D networks.

stocks by comparing USPTO patent stocks[6] in selected patent classes[7]; Figure 4 shows Germany's patent stocks relative to India's even in a technology area that we typically consider India – and not Germany – to be specialists in, and illustrates that in most cases, emerging economies – even outliers like India – have had a significantly smaller knowledge endowment throughout the time periods in which multinationals were beginning to conduct R&D there. This is significant because innovations are the result of the combination of existing knowledge (Fleming 2001), so that lack of access to the relevant cumulative knowledge can damage innovation. Hence, if multinationals wish to utilize the cheap and abundant human capital in those countries, the local inventors will need access to the relevant specialized knowledge stocks.

2.2 The Challenges of Knowledge Transfer Across Geographic Distance

Providing inventors with access to the relevant knowledge stocks that are not available locally requires knowledge transfer across geographic distance. The primary difficulty with this is that distance creates many obstacles for the transfer of knowledge (e.g. Argote, Mcevily, & Reagans, 2003; Audretsch, 1998; Patel & Pavitt, 1991). It is well established in the literature that an important rationale for the existence of MNCs is their ability to transfer knowledge more efficiently than via external mechanisms (Teece 1977), but even within a firm the challenges inherent in transferring knowledge continue to exist (Teece 1977; Szulanski 1996; Singh 2008). Hence, multinationals must find effective mechanisms to transfer knowledge from US headquarters to foreign affiliates and to facilitate learning among local inventors with insufficient access to knowledge in certain technological areas. In locations where local knowledge

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[6] Since 1980, and depreciated by 20%. The stocks do not include patents by US multinationals in these countries. The data section provides more detail.

[7] Teece; Gabriel Szulanski, 'Exploring Internal Stickiness: Impediments to the Transfer of Best Practice Within the Firm', *Strategic Management Journal*, 17.Winter Special Issue (1996), 27–43 <https://doi.org/10.1002/smj.4250171105>; Jasjit Singh, 'Distributed R&D, Cross-Regional Knowledge Integration and Quality of Innovative Output', *Research Policy*, 37.1 (2008), 77–96 <https://doi.org/10.1016/j.respol.2007.09.004>. show that that patent stocks can reflect the more fundamental determinants of the national innovative capacity of a country.

sources in given technological areas are inadequate, R&D labs might rely on the internal knowledge or expertise of their parent company to overcome the barriers of both the local knowledge shortages and the geographic distance separating them from other knowledge sources.

Strong internal linkages are one mechanism for MNCs to use for sourcing and integrating knowledge across locations within a multinational firm (Nobel and Birkinshaw 1998; Alcacer and Zhao 2012; Kogut and Zander 1993). One such internal linkage is personnel mobility, which has been well-documented as an effective method for facilitating knowledge flows (Almeida and Kogut 1999; Rosenkopf and Almeida 2003) since tacit knowledge is embedded in individuals. Polanyi (1958) in particular notes that the best way to transfer tacit knowledge is from master to apprentice, and Branstetter, Li, and Veloso (2016) and Berry (2014) posit that international co-invention might serve as a mechanism for facilitating knowledge transfer. Although geographic distances affect the costs of transportation and communication (Ghemawat 2001) and can mean it is not cost-effective or feasible to physically move the master to the apprentice or vice versa, virtual collaboration can still be effective in facilitating learning and knowledge transfer under the right conditions (Gibson and Gibbs 2006; Cummings and Teng 2003). And McEvily and Marcus (2005) argue that joint problem solving can help geographically separated team members transfer complex and difficult-to-codify knowledge.

2.3 A Formal Theory of Knowledge Transfer Within Foreign Affiliate Research Streams

In this paper, we hypothesize that MNCs utilize home country inventors on foreign affiliate inventor teams as a knowledge transfer mechanism to overcome challenges in knowledge transfer in general and the lack of host country knowledge sources in emerging economies in particular. We observe that US inventors are often present on foreign affiliate inventor teams at the beginning of a research stream but that their presence declines over the lifecycle of the research stream, and we hypothesize that this illustrates home country inventor learning. In other words, as host country teams learn from home country inventors, the delta in host versus home country knowledge declines over time, and so does the need for US inventors on foreign affiliate inventor teams.

We describe this process of knowledge transfer using a simple model, where all relevant variables are described in Table 1. In this model, a patent is produced in each period of a given research stream by either a foreign inventor team or by a foreign inventor team with an American inventor. A firm decides whether a team should have an American inventor on their team with the following maximization problem, where they trade off the cost of the inventors with the value of the idea:

$$\max\{\theta_F\mu - nw_F, \theta_A\mu - w_A - (n-1)w_F\}$$

The value that a firm can get from an idea is a function of the idea itself (μ) and the knowledge of the inventors working on that idea (θ), and the cost is the wage of each inventor (w) times the number of inventors (n). Foreign inventor knowledge (θ_F) varies by country, but will always be less than one in t=0. American inventor knowledge (θ_A) is normalized to equal one[8]. The sophistication of an idea comes as a random shock following a uniform distribution and can range from $\mu=0$, which is an unsophisticated and incremental idea that requires no inventor knowledge, to $\mu=1$, which represents a very sophisticated idea paving new directions that requires substantial inventor knowledge. Hence, if a firm includes an American inventor on the team, they will always receive the full value of the idea μ, while the value of the idea will be diminished to some degree by having a fully foreign team. However, American inventors also cost more ($w_A > w_F$). Therefore, a firm will choose to have an American inventor on the team (A=1) if:

$$\theta_A\mu - w_A - (n-1)w_F > \theta_F\mu - nw_F \qquad (1)$$

Which simplifies to:

$$\mu_t > \frac{w_A - w_F}{\theta_{At} - \theta_{Ft}} \qquad (2)$$

[8] We recognize that American inventors do not actually have perfect knowledge, but in terms of global scientific knowledge at a given point in time, the US is typically on the global technological frontier.

This means that when deciding whether to include an American inventor on the team in a given time period, the firm will weigh the difficulty of the idea compared to the wage differential and the knowledge differential in that time period. If the wage differential is larger than the knowledge differential, a firm will never choose to use an American inventor on a foreign affiliate inventor team, but if the wage differential is smaller than the knowledge differential, a firm will compare the difference to the difficulty of the idea. In this way, there will only be an American inventor on the team if the idea is sufficiently difficult and if the knowledge gap is sufficiently large relative to the wage gap.

Since $\mu \sim U(0,1)$,

$$\Pr(A = 1)_t = \Pr\left(\mu_t > \frac{w_A - w_F}{\theta_A - \bar{\theta}_{Ft}}\right) = 1 - \frac{w_A - w_F}{\theta_A - \bar{\theta}_{Ft}} \tag{3}$$

The probability of including an American inventor on the team will change over time, based on the sophistication of the idea (which is random) and the foreign knowledge stock, which will grow from the transfer of knowledge, described shortly. As $\bar{\theta}_{Ft}$ increases over the course of the research stream, Pr(A=1) will shrink.

We now describe the knowledge transfer process. Every time a US inventor works with a foreign inventor, they transfer α knowledge, where $0 < \alpha < 1$, such that the foreign inventor will gain knowledge in this fashion: $\theta_{Ft} = \theta_{Ft-1} + \alpha(1 - \theta_{Ft-1})$. When there is no American on the inventor team, there is no knowledge transfer[9], so $\theta_{Ft} = \theta_{Ft-1}$. But, as shown in the firm maximization problem, a US inventor will not work on a foreign inventor team in every period, so for a given research stream *i*, knowledge transfer will actually look as follows:

$$\theta_{iFt} = \theta_{iF,t-1} + 1\{A = 1\}_{t-1}\left[\alpha\left(1 - \theta_{iF,t-1}\right)\right] \tag{4}$$

[9] We can also modify this assumption to include heterogeneity in the knowledge gain process, such that knowledge gain occurs without a US inventor present as well – "learning by doing" – but at a slower rate. In other words, when there is a US inventor involved, foreign inventors gain knowledge as $\theta_{Ft} = \theta_{Ft-1} + \alpha_{hi} * (1 - \theta_{Ft-1})$ but when there is no US inventor involved, foreign inventors gain knowledge as $\theta_{Ft} = \theta_{Ft-1} + \alpha_{lo} * (1 - \theta_{Ft-1})$ where $0 < \alpha_{lo} < \alpha_{hi} < 1$.

When averaged across research streams in the same technology class, firm, and country, the knowledge transfer process looks like:

$$\bar{\theta}_{Ft} = \bar{\theta}_{F,t-1} + \alpha \Pr(A=1)_{t-1}(1-\bar{\theta}_{Ft-1}) \qquad (5)$$

Which can be rewritten as:

$$\bar{\theta}_{Ft} = \theta_{F0}(1-\alpha)^t + \alpha(1-\Delta w)\sum_{n=0}^{t-1}(1-\alpha)^n \qquad (6)$$

For all t>0. Note that when t=0, $\bar{\theta}_{Ft} = \theta_{F0}$.

Comparative statics then provide us with three formal hypotheses:

H1: *The initial propensity to have a US inventor on a foreign affiliate inventor team will be higher in countries with low initial knowledge stocks than in countries with high initial knowledge stocks.*

$$\boldsymbol{\frac{\partial Pr(A=1)_{t=0}}{\partial \theta_{F0}} = -\frac{w_A - w_F}{(\theta_A - \theta_{F0})^2} < 0}$$

H2: *Over the course of a new research stream in a foreign affiliate, the likelihood of including US inventors on foreign affiliate inventor teams decreases, on average across countries and technology areas.*

$$\boldsymbol{\frac{\partial Pr(A=1)}{\partial t} = \frac{\partial}{\partial t}\left[1 - \frac{w_A - w_F}{\theta_A - (\theta_{F0}(1-\alpha)^t + \alpha(1-\Delta w)\sum_{m=0}^{t-1}(1-\alpha)^m)}\right] < 0}$$ [10]

H3: *The rate of decline in the propensity to have a US inventor on a foreign affiliate inventor team will be steeper in countries with low initial knowledge stocks than in countries with high initial knowledge stocks.*

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[10] We can see that this is true by taking each component separately. Let the denominator $\theta_A - \theta_{F0}(1-\alpha)^t - \alpha(1-\Delta w)\sum_{m=0}^{t-1}(1-\alpha)^m = g(t)$ and let the numerator $w_A - w_F = f$. By the quotient rule, $\frac{d}{dt}\left(\frac{f}{g}\right) = \frac{f'g - fg'}{g^2}$. Since we know $g^2 > 0$ and $f'g = 0$, the only piece that is left is fg', which we find is less than zero. Hence $\frac{d}{dt}\left(\frac{f}{g}\right) > 0$ and $\frac{d}{dt}\left(1 - \frac{f}{g}\right) < 0$.

$$\frac{\partial}{\partial \theta_{F0}}\left[\frac{\partial Pr(A=1)}{\partial t}\right] < 0$$ [11]

We test these hypotheses utilizing comprehensive Bureau of Economic Analysis (BEA) data on U.S. multinational companies combined with patent data on these companies from the United States Patent and Trade Office (USPTO).

3. Empirical Design

3.1 Data

We use a combination of two sources of data to generate a unique dataset for analysis of US multinational innovative activity abroad.

The first is the Bureau of Economic Analysis's (BEA) annual surveys on U.S. Direct Investment Abroad. BEA is under a congressional mandate[12] to track investment into and out of the United States, and as such, their data comprise the most comprehensive available data on US multinational activity abroad. The database contains financial and operating characteristics of both the US parent companies and their foreign affiliates, including R&D expenditures, which is the primary variable of interest for this paper. We constructed a panel dataset of this activity from 1999 through 2012[13]. The panel contains 3,807 firms with multinational activity, of which 2,022 firms report R&D expenditures either in the US or abroad. Each firm may report on a consolidated basis for multiple affiliates in the same country under certain

[11] Once again, we can see this is true by taking each component separately. Once again, let denominator $\theta_A - \theta_{F0}(1-\alpha)^t - \alpha(1-\Delta w)\sum_{m=0}^{t-1}(1-\alpha)^m = g(t)$. Also let $\frac{d}{dt}[\alpha(1-\Delta w)\sum_{m=0}^{t-1}(1-\alpha)^m] = c$. Then we can rewrite $\frac{\partial}{\partial \theta_{F0}}\left[\frac{\partial Pr(A=1)}{\partial t}\right] = \frac{\partial}{\partial \theta_{F0}}\left[\frac{-(w_A-w_F)\theta_{F0}ln(1-\alpha)(1-\alpha)^t-(w_A-w_F)c}{g^2}\right]$. Let the numerator be h and the denominator be j. Then since $h'j = g^2[-(w_A - w_F)ln(1-\alpha)(1-\alpha)^t] > 0$ and $hj' = 2g[-(1-\alpha)^t] < 0$, $\frac{\partial}{\partial \theta_{F0}}\left[\frac{\partial Pr(A=1)}{\partial t}\right] < 0$.

[12] By the International Investment and Trade in Services Survey Act. The data are collected for the purpose of producing publicly available aggregate statistics on the activities of multinational enterprises.

[13] The most extensive data are collected in benchmark years: 1999, 2004, and 2009. The reporting requirement threshold varies by year, size of the affiliate, and the parent's ownership stake. BEA estimates values of some variables of some affiliates in non-benchmark years in order to estimate a consistent universe across years. We only use the reported data in this paper.

conditions[14]. Therefore, rather than conducting analysis at the affiliate level, we aggregate all foreign affiliate activity up to the country level for a given firm for a given year.

The second source of data is US Patent and Trademark Office (USPTO) patent data and includes all utility granted patent applications through 2012. We restrict our analysis to USPTO patents, rather than JPO or EPO patents, for three primary reasons: (1) our sample is US multinationals, (2) the use of USPTO patents ensures a common standard that is close to or at the global technological frontier, and (3) the use of USPTO patents allows a comparable measure across countries. Patents are a very imperfect measure of innovation; there is heterogeneity across countries, firms, and industries in the propensity to patent. However, patenting does reflect an important piece of a country's innovative output, and it is highly correlated with other measures of innovation. Because obtaining a patent from USPTO is costly and requires that the patent is for a novel invention, the use of USPTO patents helps to ensure that the counted inventions are close to the technological frontier. It also ensures that a common standard is being applied. While this measure of innovation is not ideal, we believe it is the best available measure of innovation that is consistent for both cross-country comparison and across-time comparison. Furman, Porter, and Stern (2002) provide further support for our use of patenting as a comparison measure of a country's innovation; they provide an extensive overview of other measures of a country's national innovative capacity and come to the conclusion that patents are "the most concrete and comparable measure of innovative output over countries and time". We also split our patenting measures by technology class, to at least partially control for differences in propensity to patent across industries and technologies.

There are no numerical identifiers that exist in both the BEA data and the USPTO patent data, so we matched the two databases using firm names. We conducted several rounds of fuzzy matching between BEA multinationals and patent assignees using the "reclink2" Stata command, followed by manual

[14] These conditions are that the affiliates operate in the same country and same industry classification or are integral parts of the same business operation.

verification to ensure the generated matches were correct. If a firm appeared in the BEA data but not in the patent data in a given year, we assumed that it did not apply for any patents in that year. We find that 1,415 of the 2,022 firms that conducted any R&D over this time period applied for at least one granted patent over this time period, so about 70% of BEA US multinationals making R&D expenditures at foreign affiliates also patented over this time period. Finally, we restrict our sample to those US multinationals who have at least two patsents originating from a foreign affiliate in a specific IPC class[15]. Our final sample of firms is 418 US multinationals. Although this is a significant drop in sample size, these 418 firms constitute the vast majority of global R&D activity; they made up 85-90% of all foreign R&D between 1999 and 2009.

Following the literature, we consider the patent inventors' country of residence as the country where an innovation takes place, and we consider a patent as having originated from a foreign country if any of its inventors list their address as from that country[16]. Using these data, we are able not only to see whether a firm is patenting in a country, but we are also able to see the firm's R&D expenditures there using the BEA data. This means that we are uniquely able to eliminate instances where there are patents that appear to originate in a country where there is no R&D-performing affiliate.

Our final dataset is at the patent level, and varies across application year, multinational that owns it, country it originates from, and technology class. Tables 1-3 describe each variable and provide summary statistics for all variables.

3.2 Operationalized Variables

We are interested in observing how inventor team composition – and in particular the presence of US inventors – changes over the lifecycle of a research stream in a foreign affiliate.

[15] The choice of a two-patent minimum comes from the need to look at research streams. If a firm has only generated one patent in a foreign affiliate and class, then it is not possible to look at changes in inventor team composition over time.

[16] Our findings are robust to using the majority country rule (the innovation takes place where the majority of the inventors are from) and the first country rules (the innovation took place where the first inventor is from).

Dependent Variable: Presence of US inventor on an inventor team

We can directly observe inventor team composition by looking at the inventor addresses listed on each patent. If an inventor lists an address in the US, we classify that inventor as an American inventor. For each patent emerging from a foreign affiliate, we determine whether there is an American inventor on the team, and this binary variable becomes our primary dependent variable, equal to one if there is at least one American inventor on the patent, and equal to zero otherwise[17].

Research Stream

We define a research stream as the duration of patenting within a firm-country-technology class group. In other words, a research stream will begin when a firm first begins conducting research at a foreign affiliate in a new technology area. This means that there could be up to eight research streams[18] at the same foreign affiliate, each beginning in a different calendar year. It also means that a given firm could have many research streams across many countries, each beginning in different calendar years; there is variation across calendar years, firms, countries, and technology classes. We then measure the duration of each research stream in event time, with the first patent emerging from a firm-country-technology class labeled as occurring in period t=0.

In constructing the timing of the research stream, we use the application year rather than the grant year of patents since this is closer to the actual year in which the innovation occurred. We measure patenting activity by a firm i in country j by determining whether firm i has an R&D-performing affiliate in that location and whether the patent's inventors have home addresses from country j. And we infer what

[17] Our results are robust to using a continuous measure as the dependent variable instead (the percentage of US inventors on a team).

[18] The IPC system is hierarchical in nature, and therefore can be aggregated up to as few as eight sections or disaggregated down to as many as 72,586 groups. For the purposes of our analysis, we utilize the highest aggregation of eight sections, which are detailed in the appendix. Note that since we use this highest level of aggregation that this grouping is unaffected by changes in classification over time. Also note that our results are robust to different levels of aggregation.

research streams are being conducted[19] by a given firm in a given country by using IPC classes and subclasses in the PATSTAT patent data. In this way, we define the beginning of a research stream as the start of patenting within a firm-country-IPC class group, and we measure event time within this research stream as each year since patenting began. Each patent is then labeled according to its event year within the research stream.

Country Knowledge Stock

Our data also allow us to observe the relative "local knowledge stocks" of host countries. We measure each country's knowledge stock using USPTO patent counts; more patents in a particular technology class indicate that a country has greater expertise in that technological area. We also construct citation-weighted patent stocks as a robustness check. The use of cumulative USPTO patent stocks as a measure of "local knowledge stocks" or country-level innovative capacity has been used before in the literature (Furman, Porter, and Stern 2002; Chung and Yeaple 2008), but we build upon the literature by disaggregating knowledge stocks into technology-specific knowledge stocks.

When we construct country technology-specific knowledge stocks, we include all patents filed at the USPTO by foreign inventors, but we exclude US MNC patents in order to capture the "indigenous" knowledge stock. The exclusion of US MNCs is makes little difference for most countries, but can be especially important for a handful of countries like India. It is documented in the literature that multinationals typically do R&D in countries like Germany and Japan to access expertise, in which case excluding US MNC patents makes little difference. However, we argue that for some countries, multinationals are actually creating and transferring expertise to local host country inventors within their organization rather than mining it, and as such we would expect to see a sizeable gap between patents

[19] R&D expenditures by BEA parent firms and their affiliates are not broken down by different research lines, which means that it is not possible to identify the research agendas for parents and their affiliates and whether these are shifting over time using only the BEA data.

emerging from those countries that are owned by multinationals and patents emerging from those countries that are not. Figure 5, in fact, illustrates exactly that for the case of India.

Following the literature, we utilize USPTO data rather than host country patent agency data for several reasons. First, filing for a U.S. patent is costly, so we would expect firms to only file patents in the U.S. when they are more valuable. Second, the use of USPTO patents ensures a common standard that is close to or at the global technological frontier. Finally, the use of USPTO patents allows a comparable measure across countries. While this measure of innovation is not ideal, we believe it is the best available measure of innovation that is consistent for both cross-country comparison and across-time comparison.

We construct a moving cumulative stock of patents to represent the knowledge stock of a country in a particular technology area, where we use the yearly flow in 1980 to begin and then add yearly patent flow, depreciating the previous year's stock by 20% following Chung and Yeaple (2008). An alternative measure of knowledge stocks uses a moving stock of citation-weighted patent counts.

We would argue that there is significant value in grouping countries based on this framework since it allows flexibility across both classes and time. In most cases, newer R&D hubs in developing countries will have lower patent stocks than older R&D hubs. Figure 4 illustrates a specific case, that even in the physics technology class – which encompasses patents related to computing, an area that is commonly considered a specialty of India and not of Germany – Germany still has higher patent stocks than India. And the boxplots in Figure 6 generalize this point, showing that the distribution of patent stocks in older R&D hubs are significantly higher than in newer R&D hubs, even in 2012. However, the boxplots also illustrate that this is not universally true; some newer R&D hub patent stocks exceed old hub patent stocks in specific areas. Figure 7 shows a specific example, of China's patent stocks surpassing the UK's patent stock in the area of electric communication technique. This further illustrates the value of considering a dynamic classification that is flexible across classes and over time[20].

[20] Graphs of patent stocks over time and class by country are included in the Appendix.

High and Low Knowledge Stock Countries

In order to test hypotheses one and three, we divide our sample into "high knowledge stock" and "low knowledge stock" countries. We designate a research stream as being from a "high knowledge stock" country when that country has a greater patent stock in a particular technology class than most other countries at the point in time when the research stream begins. We can define this in several different ways, and our results are robust to all definition variants. Among the fifty countries in our sample, we define "high knowledge stock" as those country-classes above the 90^{th} (or 75^{th}) percentile in a given time period. We can use patent stocks or citation stocks, where citation stocks can be undepreciated citation counts, or can be year-adjusted, where we add average citation count per year. These designations are dynamic; a country can move between the two categories over time and across IPC classes. For example, as shown in Figure 8, all the patents in one research stream that started in China in the 1990s might be classified as emerging from a "low knowledge stock" country, while all the patents in another research stream that started in China in 2010 might be classified as emerging from a "high knowledge" country. Similarly, a country might be classified as "high knowledge stock" in some technology classes, and "low knowledge stock" in others, as shown in Figure 9, where the UK is classified as "high knowledge" in Chemistry, but "low knowledge" in basic electric elements after the mid-1990s. These two figures also illustrate the value of grouping countries based on this framework; it allows flexibility both across classes and over time in a previously unexplored manner.

Furthermore, we can see from these graphs that relatively new R&D hubs like China are gaining expertise in some technology areas, even reaching the 90^{th} percentile among countries where foreign R&D is occurring. Even more interesting is the fact that we can see traditional R&D hubs like the UK falling away from the technological frontier; as China enters the 90^{th} percentile in the H class, the UK falls away from it. This suggests an important shift in the composition of R&D and patenting around the world, and is an important area for future work.

3.3 Approach and Results

Our hypotheses encompass the level propensity to have a US inventor on a foreign affiliate research stream, the rate of decline in this propensity over the course of a research stream, and how both these levels and rates of change vary across different countries.

We test Hypothesis 1 using the following Linear Probability Model regression at the patent level for the sample of patents from the first year of a research stream (t=0):

$$US\_inventor_{ijkc} = \alpha_0 + \beta_1 HiKnowledge_{jc} + \varepsilon_{ijkc}$$

Where i is firm, j is country, k is patent, and c is technology class. *HiKnowledge* is an indicator variable that is one if the research stream is classified as emerging from a "high knowledge stock" country as defined in the data section, and US_inventor is a binary variable that is one if the patent has at least one US inventor on it and zero if the patent does not have a US inventor on it. Hypothesis 1 predicts that $\beta_1 < 0$; countries with lower initial knowledge stocks are more likely to have a US inventor on their foreign affiliate inventor team in the first period of a research stream. Table 4 shows exactly that; the initial propensity to have a US inventor on a foreign affiliate inventor team is 7-9 percentage points higher in countries with low initial knowledge stocks than in countries with high initial knowledge stocks. Each column of Table 4 shows the result for a different definition of "high knowledge stock"; hypothesis 1 appears to hold regardless of whether we measure knowledge stocks in citation-weighted stocks or simple patent count stocks.

We utilize a nonparametric approach to test Hypothesis 2, and to precisely measure the propensity to have a US inventor on a foreign affiliate inventor team and how that changes over time. We estimate the following patent-level linear probability model, written in an event study form:

$$US\_inventor_{ijckt} = \alpha_0 + \beta \sum_{n=0}^{N} 1(s - y_{ijkc} = n) + \varepsilon_{ijkct}$$

Where t is the number of years in event time since the research stream began, s is the patent application year, and y_{ijkc} is the year in which the research stream began. US_inventor is an indicator variable that is equal to one if a patent has at least one US inventor on the team and equal to zero otherwise. On the right-hand side, we have an indicator for each year of the research stream in event time. Thus, the regression tells us the propensity for a patent to have a US advisor, and how this varies over the lifetime of a new research stream in a new country. Table 5 shows the regression results, and Figure 10 and Figure **11** show these regression results graphically, with and without different fixed effects[21]. It is apparent that our hypothesis is true; there is a statistically significant decline in the propensity to have a US inventor on an inventor team over the course of a research stream. In particular, at the beginning of a new research stream, a patent has a 50-53% average probability of having a US inventor on it. This propensity then declines to about 35-40% after 12 years, with the steepest decline occurring in the first few years. The fixed effects results show the robustness of the phenomenon to country, technology class, firm, and calendar year fixed effects.

These results are also robust to including an R&D control and to excluding China and India from our sample. Modifying the dependent variable to the proportion of the inventor team that is American also yields similar results. The results are also robust to using a logit or probit specification.

Finally, we test hypothesis 3 using the same approach as for Hypothesis 2, but we run this regression on two different samples: Low Knowledge Stock countries and High Knowledge Stock countries. The baseline results are shown graphically in Figure 12[22], while Figure 13 illustrates the robustness of the results to different measures of expertise[23]. They illustrate exactly what we would expect: we see the sharpest decline in the presence of US inventors on foreign affiliate teams in countries where local knowledge sources are low.

There are several other interesting takeaways from these graphs: first, we see a convex shape that reflects diminishing returns in knowledge transfer; countries that have smaller knowledge stocks appear to have

[21] The table of regression results is in the Appendix.
[22] Baseline: Expertise measured by 90th percentile of patent stocks.
[23] The other measurements are: 90th (or 75th) percentile of patent stocks, citation stocks, and year-adjusted citation stocks. The regression results in table form are included in the Appendix.

larger marginal gains from knowledge transfer. Second, we see that it takes quite some time before the two curves converge; knowledge transfer and learning take a long time. And finally, we see that US inventors continue to be present in about 35-40% of patents, even after twelve years. This suggests that US inventors play an additional role to the one we discuss in this paper. It is possible that this additional role is the one posited by Berry (2014) or Zhao (2006), discussed below.

One concern with using linear probability modelling here is that it does not account for right hand truncation. Therefore, we also use survival models to test the robustness of our results. We approach this in two different ways. First, we can define the hazard rate as the probability that there will be no US inventors on a patent in time t of the research stream, and then graph the smoothed hazard estimates using a fully non-parametric model. This alternate specification corroborates our results; Figure 14 shows both that there is an increasing probability over time and that this probability is higher for high knowledge stock countries. Second, we can estimate the survival function answering the question "What proportion of research streams will still have American inventors on their inventor teams after 12 years". Figure 15 shows the Kaplan-Meier survival estimates and also corroborates our hypotheses. They show both that the proportion of research streams with an American inventor on the inventor team declines over time, and that this proportion is lower for high knowledge stock countries.

In sum, we find that both hypotheses hold true: there is a decline in the propensity for multinationals to utilize US inventors on foreign affiliate inventor teams over the course of a new research stream, and this phenomenon is more prominent in countries with lower knowledge stock.

4. Discussion

In this paper, we document a previously unexplored cross-country phenomenon: foreign affiliates of US MNCs, when starting a new line of research, often first have a US inventor on their inventor teams, but over time, local inventor teams replace US inventor-led teams within each research line. This trend holds on average across all countries and technology areas, but it is most prominent in places with lower knowledge stocks.

Although we attribute this phenomenon to a mechanism of knowledge transfer within multinationals, there are possible other explanations. In this section, we will briefly consider some alternative possibilities.

One possibility is that local inventors catch up technologically, through some mechanism besides US inventors like country-wide catchup. However, since we control for application year and country fixed effects, and our phenomenon is observed in event time, not calendar time, this is unlikely to be the explanation.

There are other reasons why a foreign affiliate might want to have a US inventor in the early stages of setting up an R&D facility there. Rather than transferring technical knowledge, the US inventor could be transferring organizational and institutional knowledge or building relationships with the local inventors. The foreign affiliates could be overcoming the so-called "liability of foreignness" by importing organizational capabilities of the parent firm (e.g. Zaheer, 1995). But this would suggest that we would only see this phenomenon at the start of a foreign R&D lab's existence. Instead, we only observe the phenomenon when we separate research streams, some of which begin years after the R&D lab is started. In addition, this view does not directly contradict our own; we argue that at least part of the US inventor's role is as a communication and integration link to the MNC's US headquarters. However, it seems implausible that this would be their only role on an invention team; a manager could play the same role if integration were the only purpose.

A third possible mechanism is that rather than utilizing American inventors less over time, foreign affiliates are utilizing local inventors more over time (1) to better access local diversity in technology, resources and capabilities or (2) to better access and respond to the local market. The first would imply that we would expect to see a steeper decline in the propensity of having US inventors on foreign affiliate teams in places with large knowledge stocks, like Germany. However, instead we see that these are precisely the places where the phenomenon is least apparent. Likewise, the local markets explanation would suggest that knowledge stocks play no role whatsoever in the presence of US inventors on inventor teams and that we would see the steepest decline in places that have large markets. This would seem to line up closely with the fact that China and India – two countries with enormous markets – have among the steepest declines. However, we still observe a decline in smaller countries like Malaysia and, on average, our analysis seems to suggest that knowledge stocks do in fact matter in explaining where the phenomenon will be strongest.

Three other prominent theories explaining the presence of US inventors on foreign affiliate inventor teams arise from Berry (2014), Zhao (2006), and Foley & Kerr (2013). Zhao posits, in her 2006 paper, and in a followup paper (Alcacer and Zhao 2012), that home country inventors on foreign affiliate inventor teams serve as a mechanism for reducing knowledge expropriation in countries with weak IPR protection. Berry posits that the presence of home country inventors on foreign affiliate inventor teams is related to manufacturing integration. While neither of these theories explain the decline in the presence of US inventors over the course of a research stream, they could explain their continued – lesser – presence 12 years into the research stream. Foley and Kerr (2013), and later Kerr & Kerr (2018), highlight the role of ethnic ties, arguing that US-based ethnic innovators facilitate US MNC foreign R&D in new foreign regions. This theory complements our own; ethnic ties may form an important component of the means by which the US inventors in our paper transfer knowledge.

Our paper is also closely related to Berry (2015), who – like us – compares home country technological innovation and foreign innovation, and posits that when home country technological innovation dominates foreign innovation, then a parent firm's technological knowledge will be especially important. However, she does not explore the mechanism by which a parent's technological knowledge is transferred.

A final point of discussion is whether our findings imply that US inventive activity is being replaced by foreign inventive activity. Previous work (e.g. Macher & Mowery, 2008) has found that at least some industries, inventive activity by US MNCs has remained US-centric. Our study seems to imply that at least some significant R&D activity is indeed shifting abroad. However, the continued importance of US inventors in foreign affiliate inventor teams suggests that rather than a substitution effect, there is instead a complementary effect within US MNCs. This is an area for future research.

5. Conclusion

In this paper, we observe that US multinationals conduct a surprising amount of R&D in low income countries, as shown in Figure 1, apparently able to overcome the barrier of relatively low levels of access to the technological frontier of knowledge in those countries. We explain this puzzle by introducing a mechanism by which US multinationals can overcome challenges in knowledge transfer and in inadequate local host country knowledge stocks. Our empirical analysis suggests that US multinationals utilize US inventors on foreign affiliate inventor teams to facilitate knowledge transfer to local inventors. We also find that firms' use of this mechanism varies depending on the local knowledge stocks of the country in which they are conducting R&D. US inventors are present on foreign affiliate inventor teams at the beginning of a research stream more frequently in countries with low knowledge stocks, and their presence declines more steeply, reflecting greater initial marginal returns.

We believe our paper helps explain how multinationals are able to manage and integrate increasingly dispersed global R&D networks, and how they are able to conduct R&D in locations that may have inadequately trained local inventors. We also provide some evidence that current theories of the knowledge-sourcing motivation behind the globalization of R&D may be incomplete; R&D is occurring in locations with relatively low knowledge stocks.

Our findings also have important implications for policymakers. We illustrate how countries can gain expertise in certain technical areas, and we describe an additional means by which multinationals might help poor countries escape the knowledge trap (Jones 2014): by providing a mechanism through which local inventors can become specialized in a technical area. We also observe empirically that some countries that have historically been important R&D hubs are falling behind the technological frontier.

There are limitations to this study. Our context is US multinationals, and therefore our results may not apply to multinationals from other parts of the world. Our measure of knowledge stock is a crude one; some countries – like Japan - are more prone to patenting than others, but their local knowledge stocks may not actually be greater than other countries – like Israel – that do not tend to patent very much. Finally, there may be other mechanisms that are causing the decline in the propensity to have US inventors on foreign affiliate inventor teams, although we are able to rule out many of these other possibilities.

We see several areas for future research. First, it would be useful to explore some of the alternative proposed mechanisms. Second, we do not explore whether the patents generated by local inventor teams later on in a research stream are equally as innovative as those first patents with a US inventor on the team; does complete knowledge transfer happen, so that local host country inventors gain equal expertise to American inventors? Or is the transfer of knowledge purely geared toward the division of labor, where many countries become specialized in a less sophisticated or specialized type of research than the US? This has important implications for whether foreign inventors are substituting for American inventors, or whether they provide a complementary role. Third, the fact that US inventors continue to be involved about 1/3 of the time - even after two decades working within a research stream – suggests that they play an important role even after the initial training or knowledge transfer period, one that we have not explored here. This also suggests that foreign inventors are not fully substituting for US inventors; US inventors continue to play a central role in US MNC R&D operations. Fourth, in some instances, the propensity to have US inventors on foreign affiliate teams seems to increase over time. Although we have not tested it here, one possible explanation is that when US MNCs acquire a local firm, as the local firm becomes integrated into the MNC, these local inventors begin to work more and more closely with the US inventors in the corporation. In this way, more and more inventor teams have a US inventor as the firm becomes integrated. Fifth, we have not explored what affects "alpha" or the efficiency of knowledge transfer. Our analysis here focuses on country-level variation, but firm-level variation almost certainly also plays an important role. Sixth, for the purposes of our model, we dramatically simplified the reasons for which multinationals conduct R&D in the so-called “new hubs”, attributing this only to low costs in our model. This is almost certainly not the only reason that multinationals conduct R&D in those locations. Further work is needed to understand the motivations behind MNC foreign R&D activity, and particularly in understanding the motivations in relatively low knowledge stock places. Finally, our knowledge stock analysis suggests that some countries may be falling behind the technological frontier in some technology areas. Exploring this phenomenon and the possible causes is another area for future work.

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Figure 1: Developing Countries are now a Major Destination for Foreign R&D

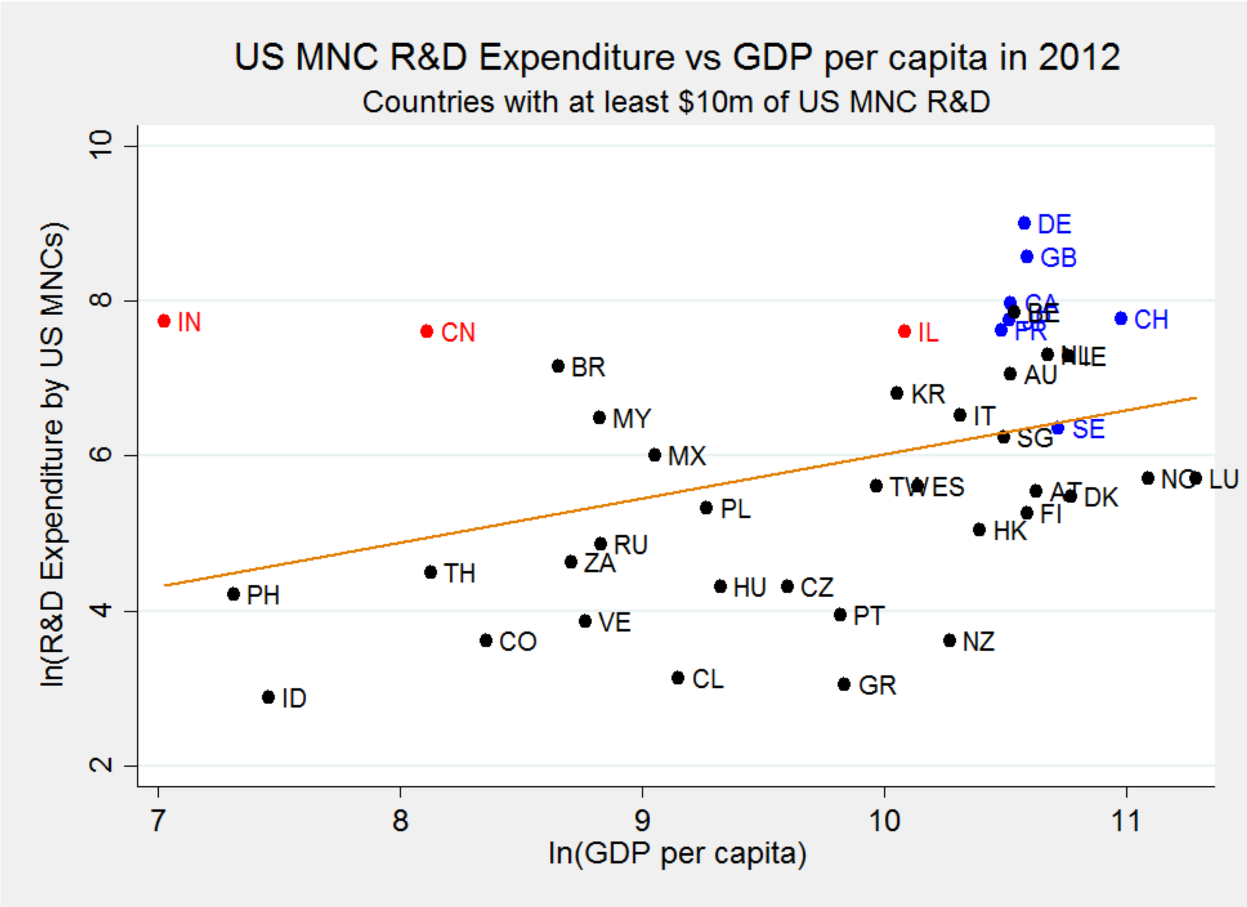
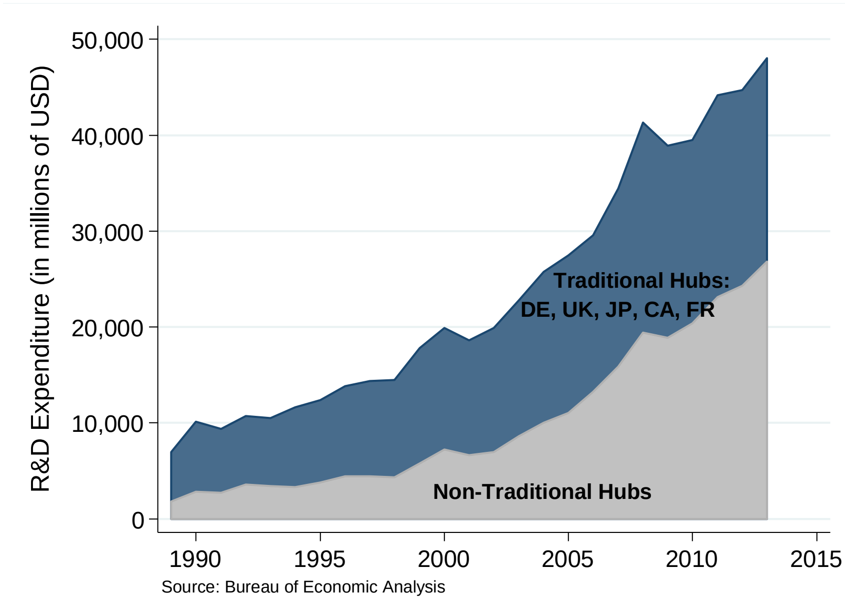
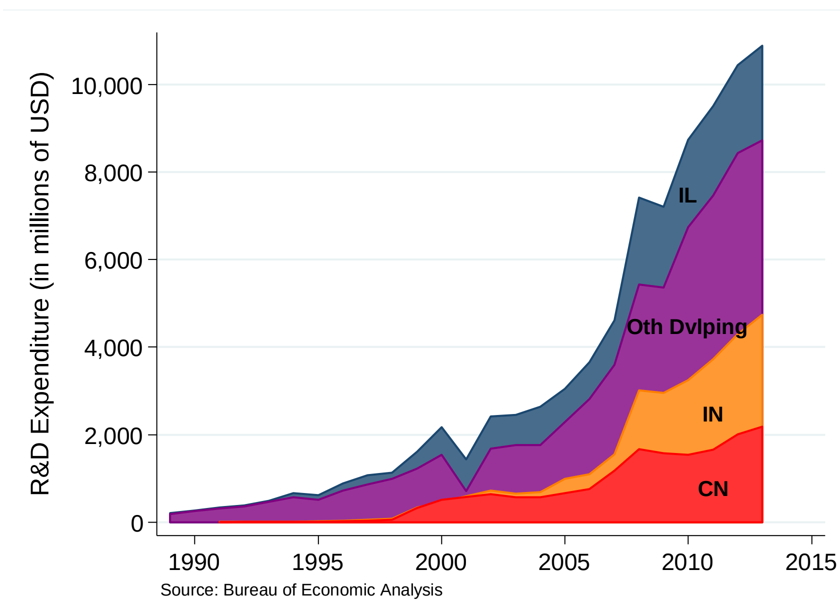


Figure 2: The Rise of Non-Traditional R&D Hubs



Note: "Non-Traditional Hubs" include all countries with the exception of Germany, the UK, Japan, Canada, and France.

Figure 3: The Rise of R&D Hubs in Developing Countries (+ Israel)



Note: Developing countries defined using the IMF World Economic Outlook and are a subset of the "non-traditional hubs".

Figure 4: Patent stocks in Germany vs India, in the physics class

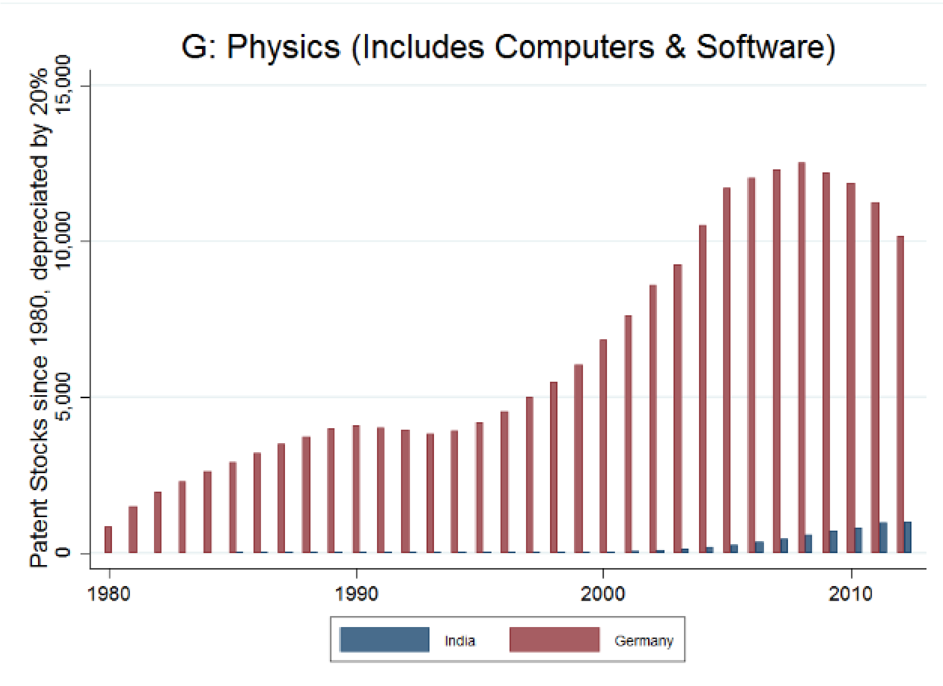


Figure 5: India's Patent Stocks, with and without US MNCs

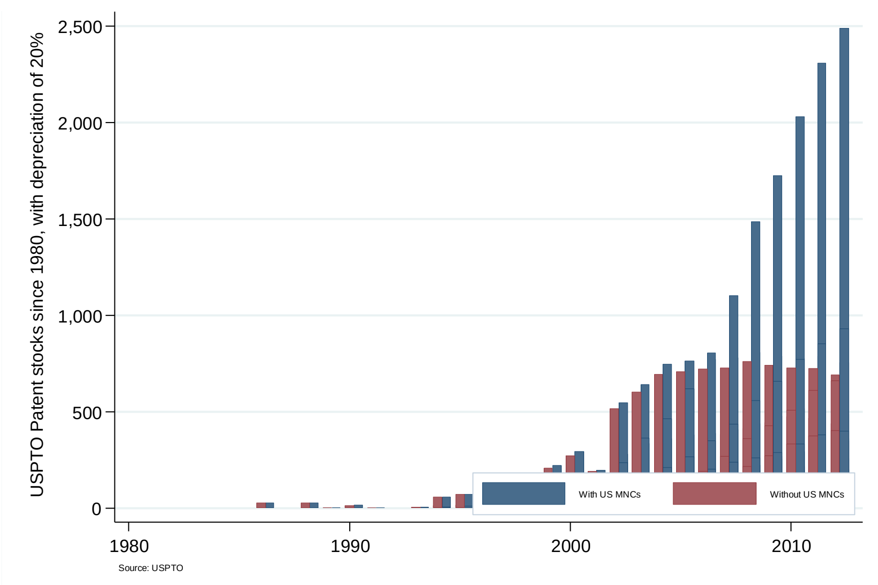
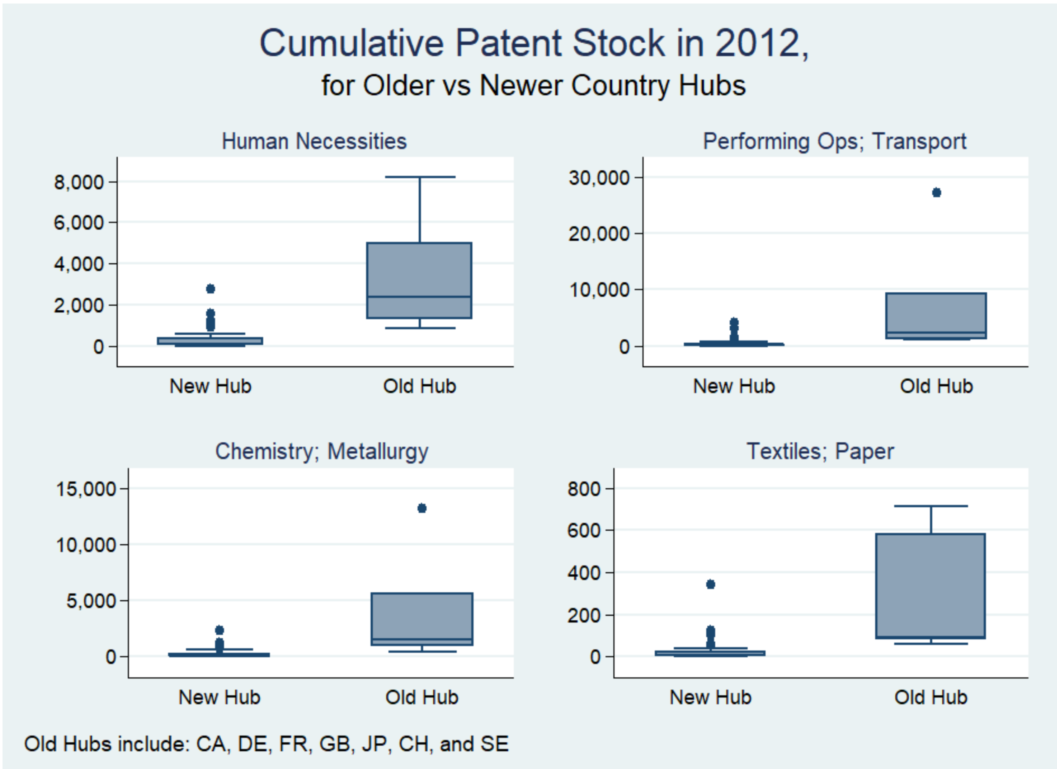


Figure 6: Cumulative Patent Stocks in Old and New Hubs by 2012



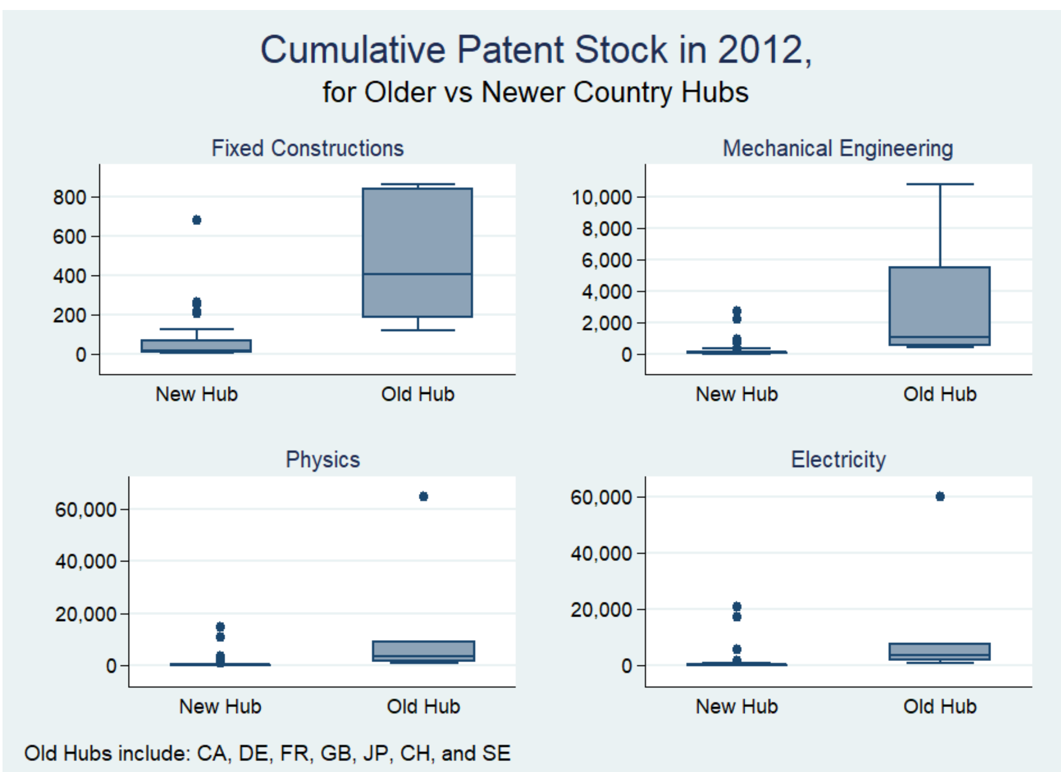


Figure 7: Patent stocks in China vs UK, in the electricity IPC class

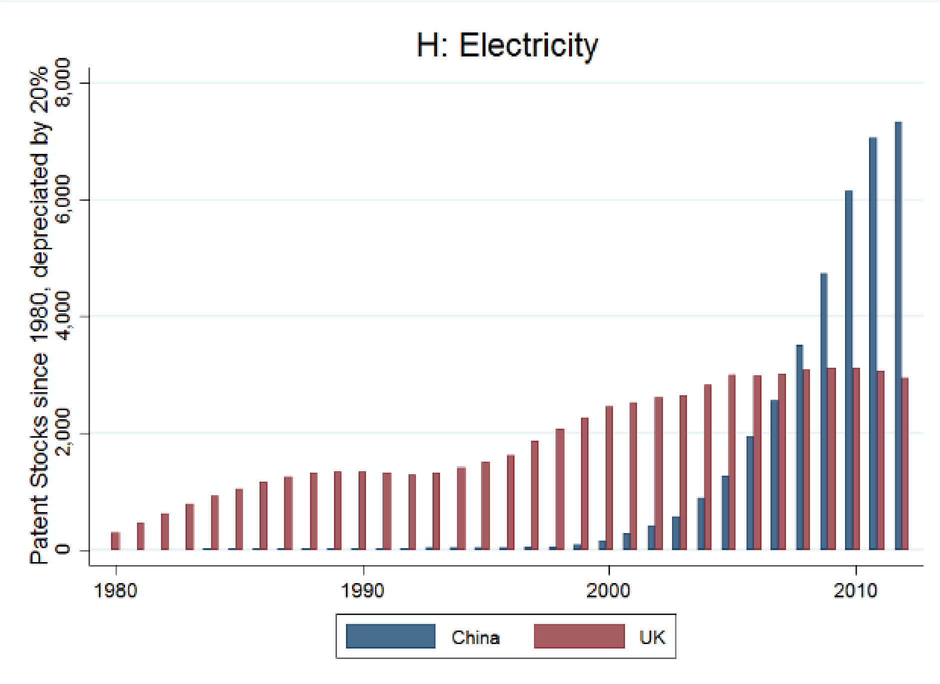


Figure 8: China's electricity patent stocks relative to the 90th percentile of electricity patent stocks

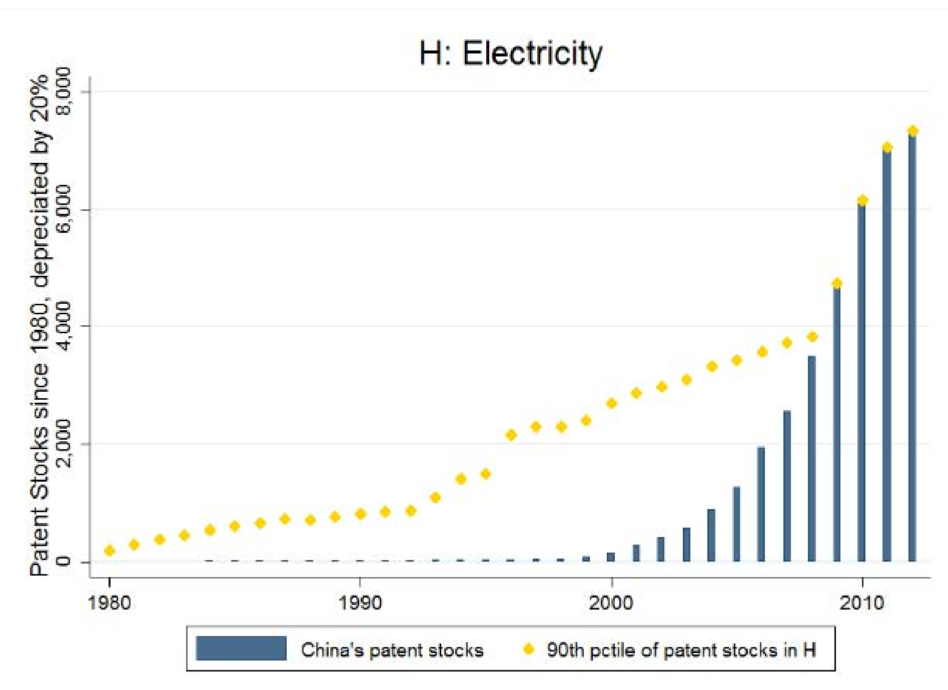


Figure 9: UK's patent stocks in Chemistry vs in Electricity

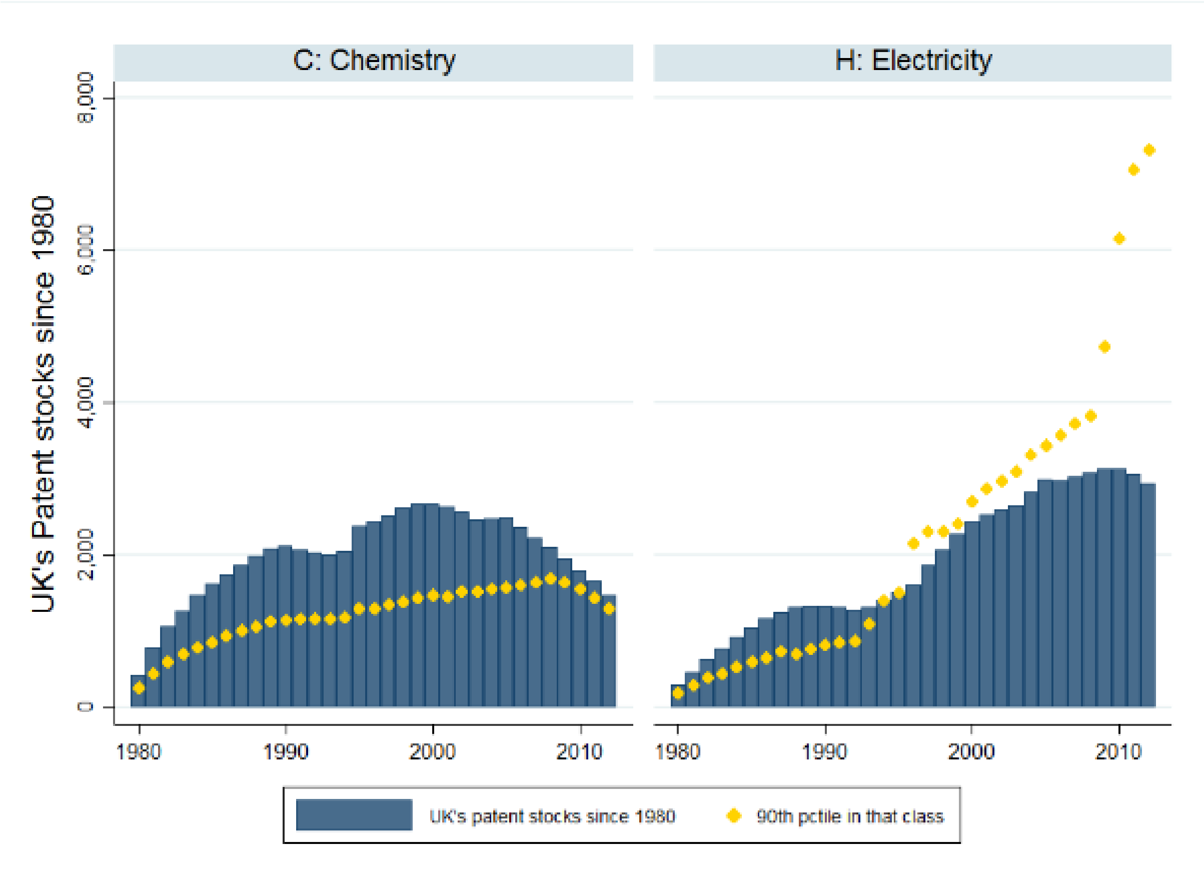


Figure 10: Testing Hypothesis 2, Decline in the Propensity to have a US inventor on a Foreign Affiliate Research Team

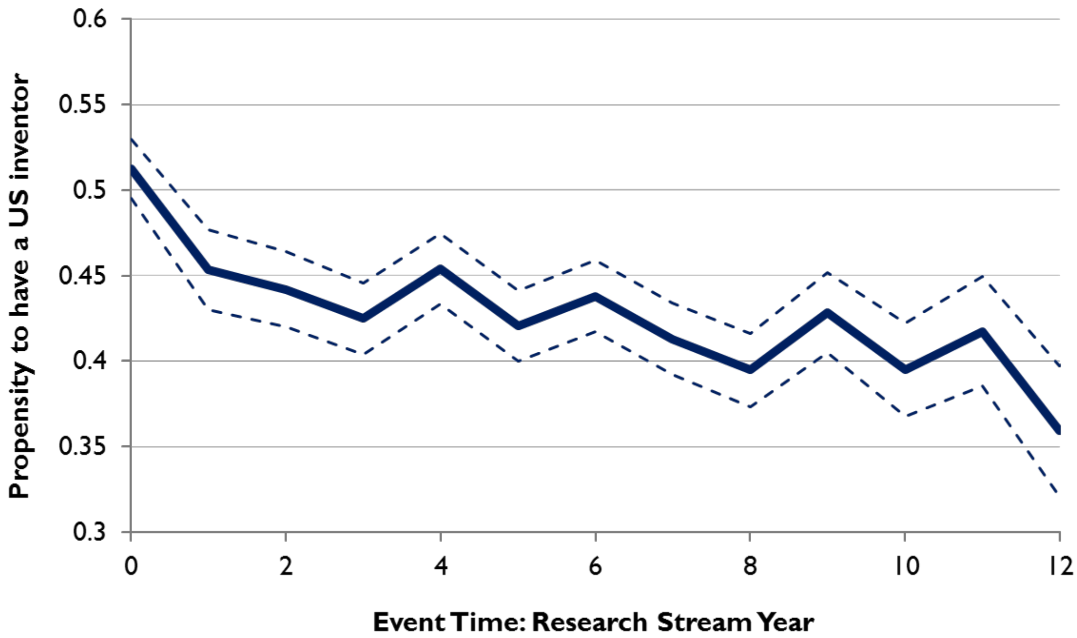


Figure 11: Testing Hypothesis 2, Decline in the Propensity to have a US inventor on a Foreign Affiliate Team, Robustness to Fixed Effects

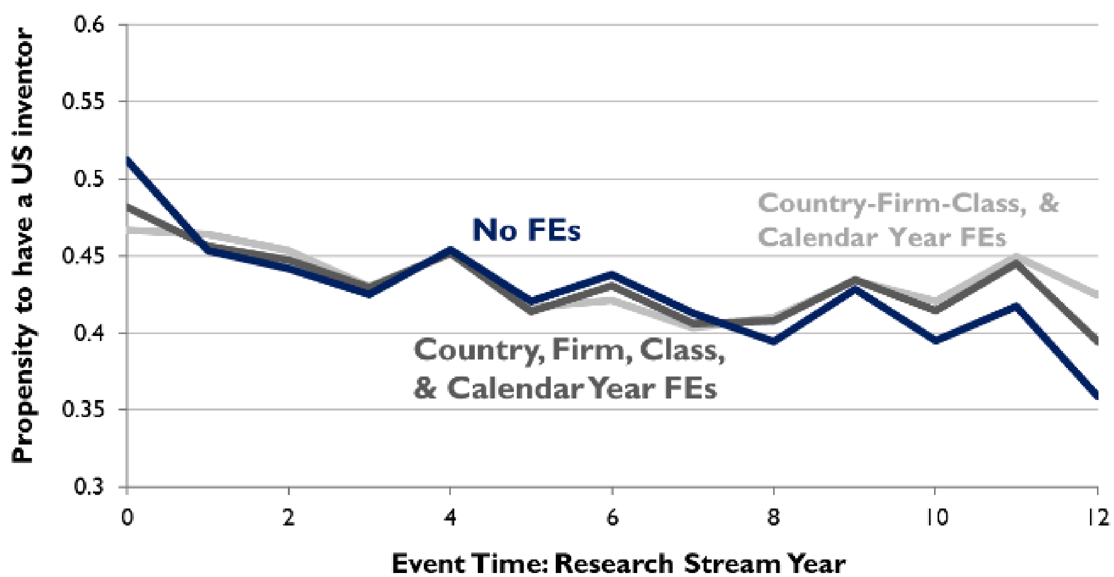


Figure 12: Testing Hypothesis 3, High vs Low Knowledge Stock countries, as measured by the 90th percentile of patent stocks

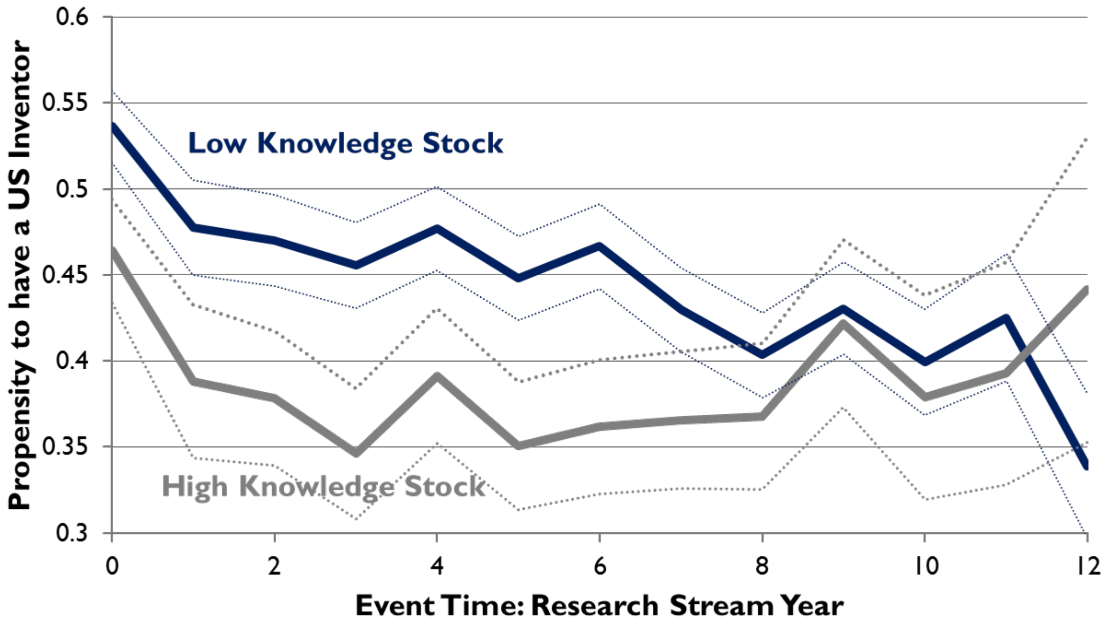


Figure 13: Testing Hypothesis 3, High vs Low Knowledge Stock countries, Robustness to different definitions

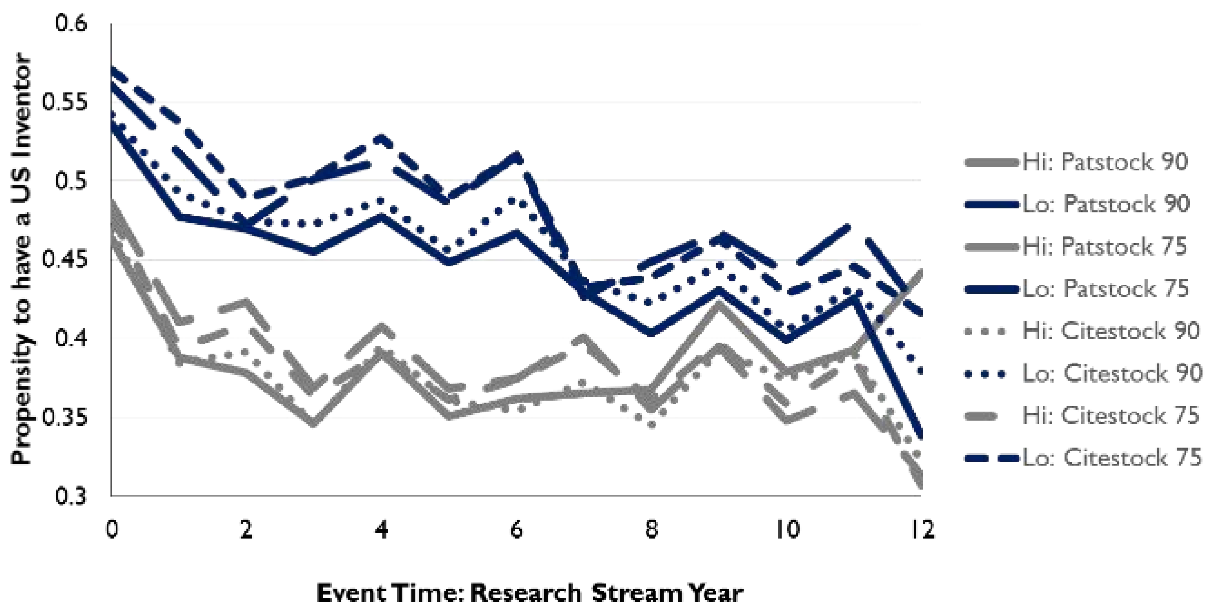
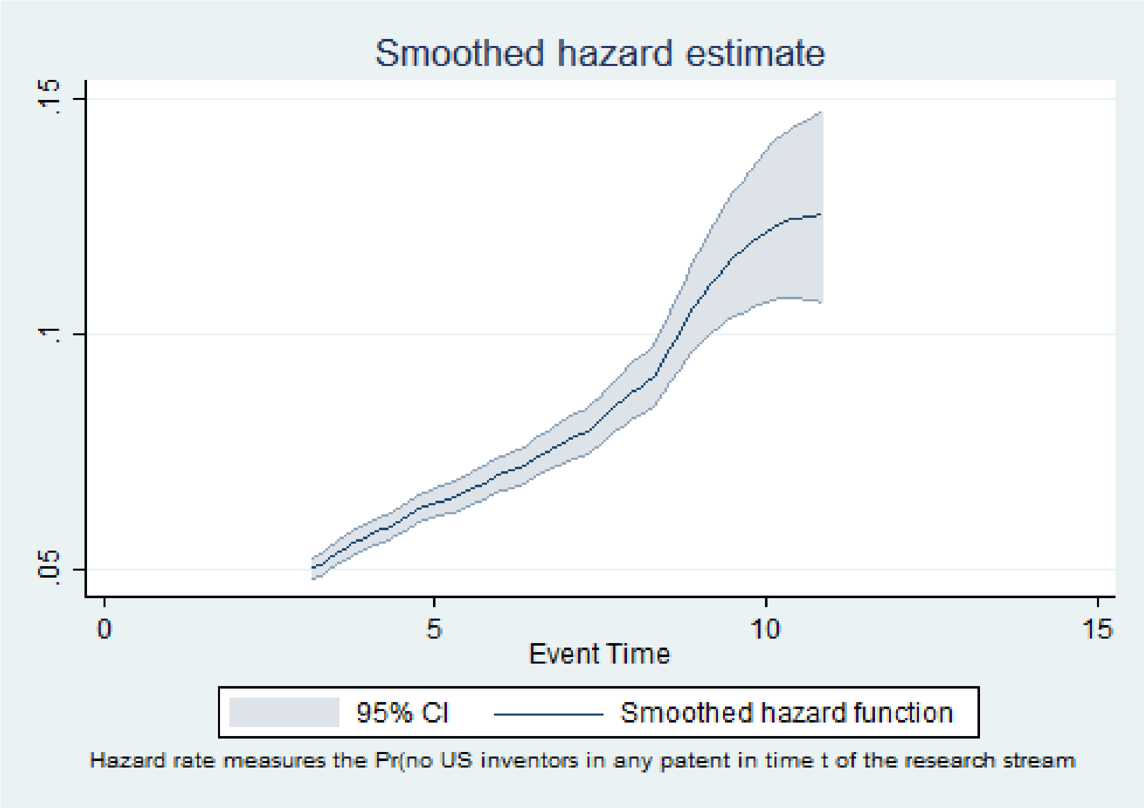


Figure 14: Hazard Estimates



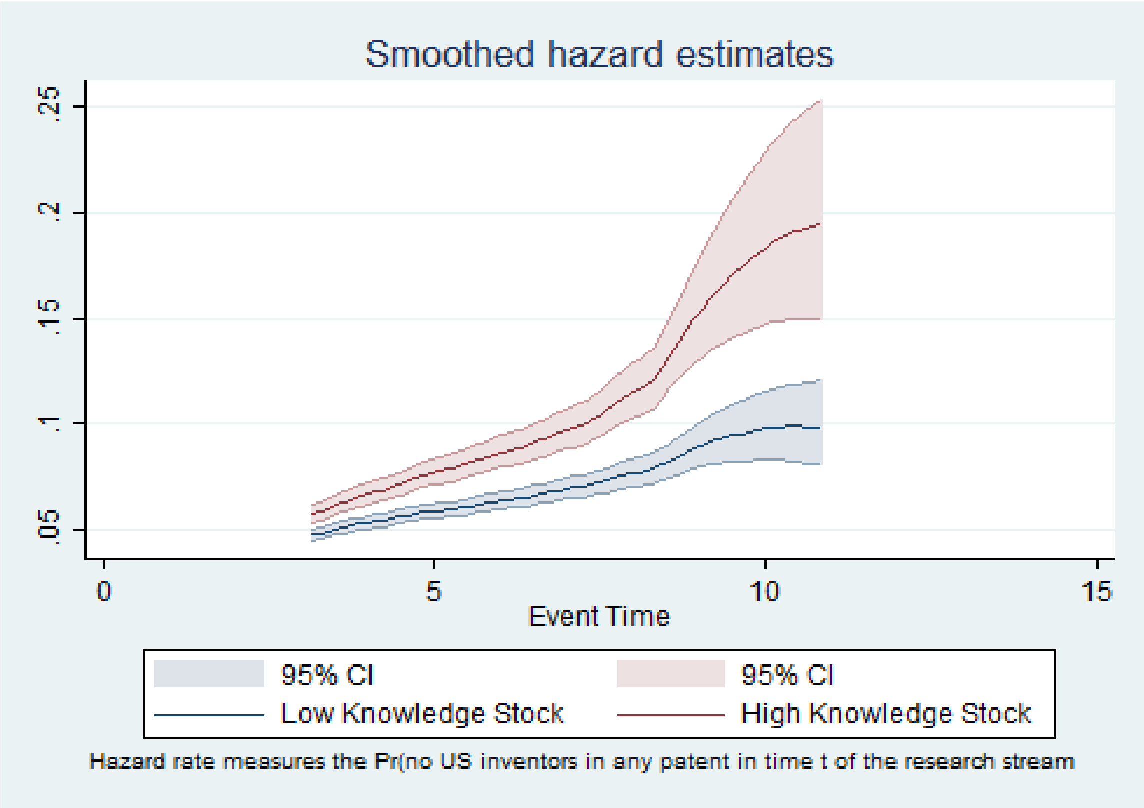
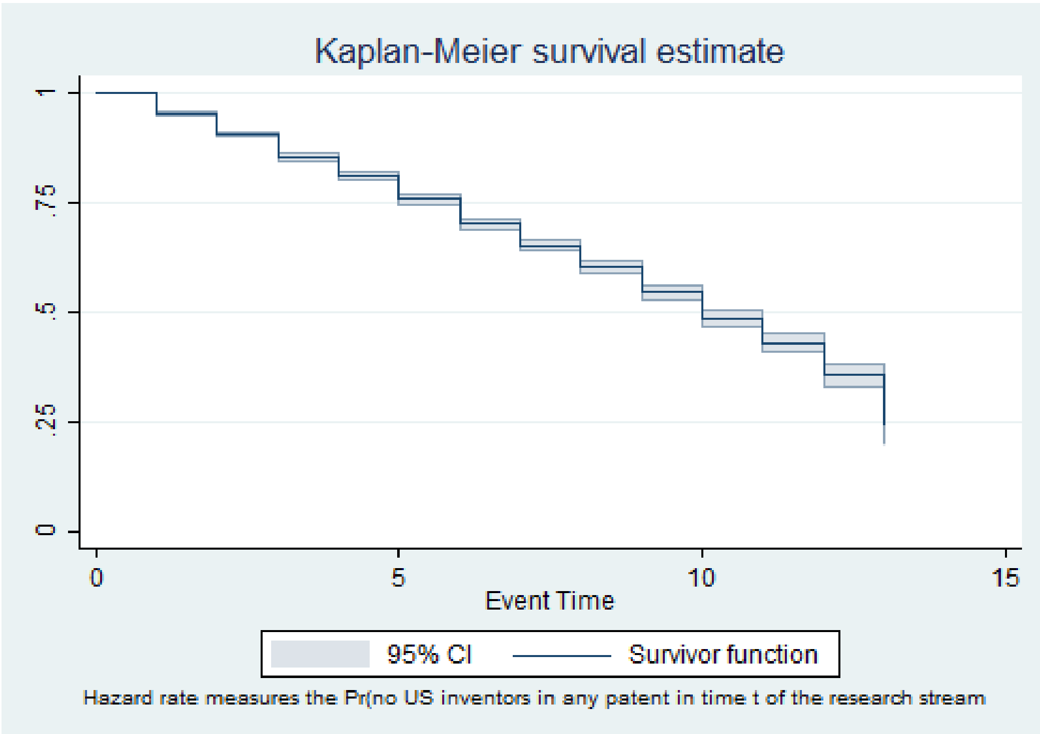


Figure 15: Kaplan-Meier survival estimates of the proportion of research streams that will still have American inventors on their inventor teams



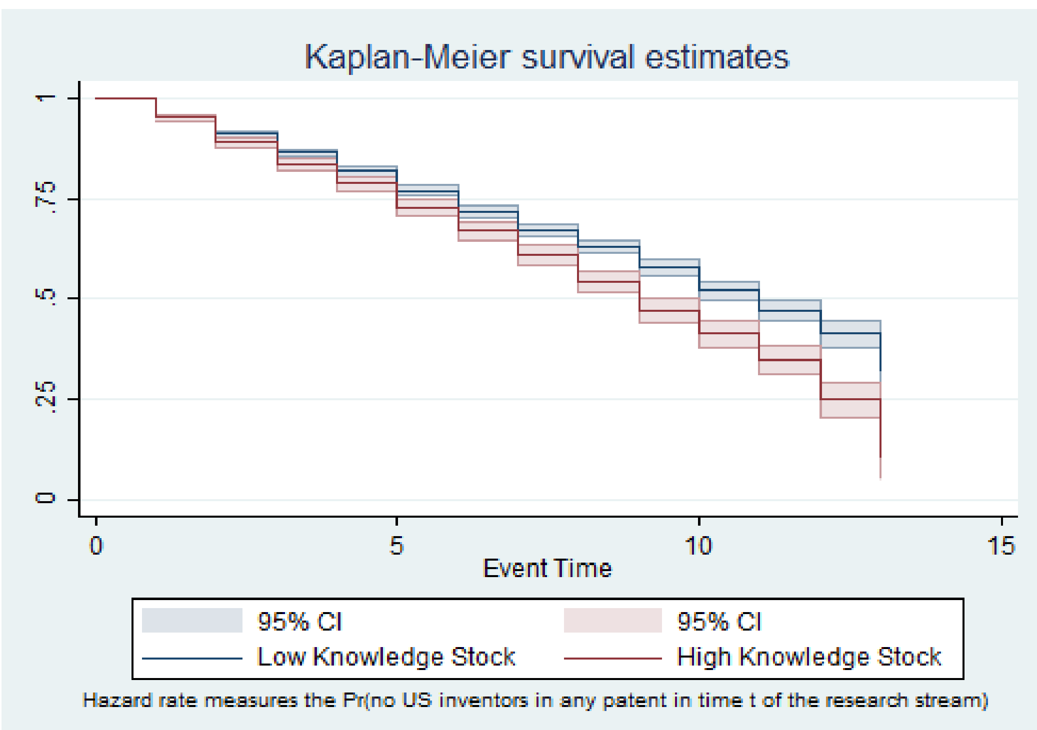


Table 1: Variable Definitions from a Formal Theory of Knowledge Transfer

Variable	Represents	Takes values of	Varies…
θ	Inventor knowledge stock	Foreign inventor knowledge stock(θ_F): $0 \leq \theta_F \leq 1$ American inventor knowledge stock: $\theta_A = 1$ (in all time periods)	At the country level And θ_F grows over time
μ	idea sophistication	μ~U(0,1) μ=0 : an unsophisticated / incremental idea μ=1 : a sophisticated idea paving new directions	Across all dimensions
w	Wage/income	Wage/income paid to foreign inventors: w_F Wage/income paid to American inventors: w_A	At the country level
α	Efficiency of knowledge transfer	0< α<1	At the research stream level
n	Team size	n≥2	At the research stream level

Table 2: Summary Statistics, overall

	N	Source	Timeframe
Research streams	1,087	BEA & USPTO	1999-2012
Patents	24,447	USPTO	1999-2012
Firms	418	BEA & USPTO	1999-2012
Countries	50	BEA & USPTO	1999-2012
IPC sections	8	USPTO	1999-2012

Table 3: Summary Statistics

Calculated across countries					
	Mean	Median	Std. Dev	Min	Max
No. of Research streams	65	27	93	1	453
No. of Patents	489	192	809	2	3,470
No. of Firms	28	11	37	1	170
No. of Tech Classes	5	6	3	1	8
Observations	50				
Calculated across firms					
	Mean	Median	Std. Dev	Min	Max
No. of Research streams	8	3	11	1	97
No. of Patents	58	12	159	2	1,730
No. of Countries	3	2	4	1	29
No. of Tech Classes	2	2	2	1	8
Observations	418				
Calculated across classes					
	Mean	Median	Std. Dev	Min	Max
No. of Research streams	404	533	282	60	924
No. of Patents	3,056	1,821	3,454	174	9,927
No. of Countries	33	35	8	21	44
No. of Firms	117	121	65	26	210
Observations	8				

Table 4: Testing Hypothesis 1, Comparing Propensity Levels in t=0

VARIABLES	(1) US inventor	(2) US inventor	(3) US inventor	(4) US inventor	(5) US inventor	(6) US inventor
Hi_>90, Pat Stock	-0.0723***					
	(0.0187)					
Hi_>75, Pat Stock		-0.0748***				
		(0.0183)				
Hi_>90, Cit Stock			-0.0733***			
			(0.0179)			
Hi_>75, Cit Stock				-0.0915***		
				(0.0182)		
Hi_>90, Cit Yradj					-0.0754***	
					(0.0180)	
Hi_>75, Cit Yradj						-0.0919***
						(0.0182)
Constant	0.536***	0.561***	0.542***	0.571***	0.542***	0.571***
	(0.0107)	(0.0146)	(0.0113)	(0.0144)	(0.0113)	(0.0145)
Observations	3,232	3,232	3,232	3,232	3,232	3,232
R-squared	0.005	0.005	0.005	0.005	0.005	0.008
F	14.93	16.73	16.78	25.42	17.61	25.57

Robust standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

Table 5: Testing Hypothesis 2, Decline in the Propensity to have a US inventor on a Foreign Affiliate Research Team

	(1)	(2)	(3)	(4)	(5)
	Pr(US inventor)	Pr(US inventor)	Pr(US inventor)	Pr(US inventor)	Pr(US inventor)
Yr 1	-0.0593***	-0.0292*	-0.0674***	-0.0603***	-0.0256
	(0.0149)	(0.0143)	(0.0148)	(0.0151)	(0.0142)
Yr 2	-0.0708***	-0.0354*	-0.0811***	-0.0712***	-0.0346*
	(0.0143)	(0.014)	(0.0145)	(0.0147)	(0.0139)
Yr 3	-0.0878***	-0.0516***	-0.105***	-0.0964***	-0.0523***
	(0.0138)	(0.0142)	(0.0144)	(0.0147)	(0.0142)
Yr 4	-0.0587***	-0.0286*	-0.0882***	-0.0803***	-0.0299*
	(0.0138)	(0.0144)	(0.0145)	(0.0148)	(0.0144)
Yr 5	-0.0922***	-0.0647***	-0.135***	-0.130***	-0.0677***
	(0.0137)	(0.0147)	(0.0147)	(0.0149)	(0.0148)
Yr 6	-0.0747***	-0.0471**	-0.126***	-0.113***	-0.0512***
	(0.0139)	(0.0153)	(0.0151)	(0.0153)	(0.0155)
Yr 7	-0.0998***	-0.0693***	-0.163***	-0.150***	-0.0759***
	(0.0138)	(0.0158)	(0.0154)	(0.0156)	(0.0161)
Yr 8	-0.118***	-0.0701***	-0.176***	-0.170***	-0.0742***
	(0.014)	(0.0165)	(0.0159)	(0.0161)	(0.0169)
Yr 9	-0.0842***	-0.0385*	-0.150***	-0.138***	-0.0471**
	(0.0148)	(0.0177)	(0.0169)	(0.017)	(0.0182)
Yr 10	-0.118***	-0.0577**	-0.197***	-0.185***	-0.0672**
	(0.0165)	(0.0201)	(0.0189)	(0.019)	(0.0206)
Yr 11	-0.0953***	-0.0285	-0.177***	-0.181***	-0.0366
	(0.0186)	(0.0223)	(0.021)	(0.0212)	(0.0229)
Yr 12	-0.154***	-0.0805**	-0.249***	-0.255***	-0.0875***
	(0.0214)	(0.0258)	(0.0246)	(0.0247)	(0.0264)
Constant	0.513***				
	(0.00879)				
Firm FEs		YES			YES
Country FEs			YES		YES
Calendar Year FEs		YES	YES	YES	YES
Class FEs				YES	YES
Observations	24,447	24,447	24,447	24,447	24,447
R-squared	0.005	0.183	0.06	0.019	0.202

Robust standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05