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Talent Flows and the Geography of Knowledge Production: Causal Evidence from Multinational Firms*

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Abstract

Leveraging a unique dataset merging patent data with all work-related migration reforms that took place in 15 countries over 26 years, we show that reforms discouraging inventor mobility decrease the patenting of MNE subsidiaries within a country, while reforms encouraging it have a positive but much smaller effect. Additionally, reforms adopted in the U.S. affect innovation in other countries in the opposite direction, highlighting the existence of a global competition for talent. Finally, we find that policies easing migration have facilitated about half of the shift in global innovation toward emerging markets.

JEL Codes: O33, O15,F22
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1 Introduction

In July 2021, a hearing at the Immigration and Citizenship Subcommittee of the U.S. House of Representatives concluded that America is losing talent to Canada because of outdated and restrictive U.S. immigration policies.[1] It is intuitive to think that migration policies, in the United States and in many other countries around the globe, are defining the global distribution of talent flows, in turn affecting important local and global economic outcomes. In this paper, we focus on this question by exploring how country-specific migration reforms have affected the local and global production of innovation.

Indeed the geography of innovation is changing rapidly. For instance, in 2019, the World Intellectual Property Organization (WIPO) reported that China alone accounted for almost half of all the world's patent filings, with India also registering impressive increases in global patent production. "Asia has become a global hub for innovation", declared WIPO Director General Francis Gurry,[2] while just a few decades ago these emerging markets constituted a negligible share of global patent production. In fact, by 2018, the 20-year growth rate of R&D activities of U.S. MNEs in foreign countries—estimated to be 6%—exceeded the growth rate of R&D within the U.S., which was estimated at 4%.[3] However, we know little about how the shift of innovation toward China, India, and other countries can be attributed to talent flows toward these countries and to weakening talent flows into the U.S.

A recently growing literature has established the important role of high-skill immigration for the *local* production of innovation.[4] However little evidence is available to understand how talent flows to a particular country can affect economic outcomes, in particular innovation, in other countries.[5] The purpose of this study is to explore the role that inventor mobility plays in changing

[1]Source: https://www.forbes.com/sites/stuartanderson/2021/07/15/house-immigration-chair-warns-us-is-losing-talent-to-canada/?sh=7ce316be5aef.

[2]Source: https://www.wipo.int/pressroom/en/articles/2019/article_0012.html.

[3]Source: The U.S. Bureau of Economic Analysis (BEA).

[4]See Lissoni (2018) for a review of this literature.

[5]One exception is the work by Glennon (2020), who finds that limitations to the H1B visa in the United States result in MNCs relocating workers to foreign subsidiaries. We build on this work by focusing on outcomes on a global scale, with particular focus on innovation using highly disaggregated patent data.

the geography of innovation. To do this, we put together a novel global dataset recording the exhaustive list of work-related migration reforms adopted in 15 countries over the period from 1990 to 2016 (61 reforms in total), which we categorize as positive or negative depending on their expected effect on the number of mobile inventors.[6] We then match them with the patenting activities of 28,443 MNEs and their 70,624 country-level subsidiaries taken from the universe of USPTO patents from PatentsView.[7] In our dataset, we can follow both MNE subsidiaries and inventors over time and, thus, identify movers across countries following the reforms. We refer to these inventors as Global Mobile Inventors, or GMIs, as coined by (Bahar et al., 2021). An inventor is considered a GMI if he or she is observed patenting in a different country with respect to the one of first appearance in the data. Our analysis considers patent outcomes of three types: i) overall patent counts; ii) global collaborative patents, or GCPs (defined by (Kerr and Kerr, 2018) as those patents with geographic footprints that cross international borders); and iii) domestic patents (patents where all inventors reside in the same country at the time of filing).

A key challenge for causal inference is that innovation trends are not necessarily exogenous to the country-level enactment of migration policies. In an effort to reduce endogeneity concerns and in order to establish causal estimates of how patenting by MNE subsidiaries is affected by migration policy changes, we employ an event study design that identifies plausibly exogenous variations in subsidiary exposure to migration reforms. In particular, we leverage the fact that subsidiaries belonging to MNEs with established habits of international human capital rotation are likely to be more responsive to policies affecting work-related migration. As expected, we empirically show that reforms relaxing migration constraints result in a larger number of GMIs flowing into exposed subsidiaries, while the opposite happens following policies deterring migration.

Our first set of results, focusing on local dynamics, finds that each additional positive reform increases the number of global collaborative patents filed by exposed subsidiaries by 6.6%, but

[6] The countries included in our data are Brazil, Canada, Chile, China, Germany, India, Japan, Mexico, the Philippines, Portugal, South Korea, Spain, Taiwan, the United Kingdom, and the United States. Patenting in these countries during the period of our study represents 80% of all the patents produced from 1990 to 2016 that appear in the USPTO data.

[7] Note that the USPTO not only records the patents filed by U.S. firms, but also includes all patents filed in other countries that subsequently registered their invention at the USPTO to be protected against U.S. competition. As such, it is widely considered an exhaustive list of major innovations across the globe.

has no effect on domestic patents; each additional negative reform decreases the number of global collaborative patents by 19% and the number of domestic patents by 24%. Negative reforms have on average stronger marginal effects on international flows of inventors relative to positive ones, resulting in a larger impact on innovation. This asymmetry of effects remains true even if we control for the leverage used by each reform and for whether it introduces major or minor changes. Overall, mobile inventors appear to be crucial determinants of the innovation capacity of countries, since we estimate that a 1% increase in the number of GMIs increases the number of patents filed among exposed subsidiaries by 1.8%.

In the second part of the paper, we explore the role that GMIs play in explaining changes in the global production of knowledge, leveraging the global nature of our dataset. First, we show that reforms adopted in the U.S. generate spillovers for other countries' innovation. In particular, we find that when the U.S. relaxes immigration constraints, the patent production of other countries is reduced, whereas when the U.S. restricts immigration, firms in other countries increase their patenting.[8] In fact, our point estimates suggest that the drop in patenting observed in other countries following the U.S.'s adoption of positive migration reforms is equivalent to almost a third of the drop observed following negative migration reforms adopted domestically. This result is of particular importance because it shows that discarding the dynamics of mobility in other countries prevents a complete understanding of global innovation dynamics. More generally it suggests that one country's loss is another country's gain when it comes to attracting talent in the context of innovation.

Finally, further leveraging the global aspect of our dataset, we show that positive migration reforms generate stronger effects in emerging markets, suggesting that policies encouraging cross-border mobility have contributed to the observed shift in the geography of innovation toward these countries. Our back-of-the-envelope calculations reveal that in the absence of positive migration reforms, the share of global innovation produced by emerging markets would have grown from 5% to 12% from 1990 to 2015, instead of reaching 25% as we observe in the data. As such, migration

[8] We test the presence of spillovers associated with reforms in all the major countries in our sample, but only the U.S. shows clear-cut results. This is in line with its status as a global leader in attracting talent.

reforms explain about half of the growth in patenting in these emerging economies.

These results contribute to three strands of the literature. First, we provide an empirical framework that establishes a causal relationship between inventor mobility and the production of innovation at the local level.[9] Here, we contribute to the nascent literature on international co-invention and MNEs' global collaborative patenting activities (Kerr and Kerr, 2018; Branstetter, Li and Veloso, 2014). In that sense, our contribution speaks to the globalization of innovation as a result of human mobility, given that part of the knowledge production we see as a result of more mobility is concentrated among cross-country collaborations. Furthermore, an important contribution in our setting is that reforms hindering mobility are detrimental for knowledge production, an effect that is quite robust and long-lasting.

Second, we contribute to a small yet growing literature exploring how firms relying on foreign workers are not only affected by the migration policies of the countries where they are located, but also by the ones adopted in countries competing for the same pool of talent. Glennon (2020) shows that the 2020 H-1B visa freeze in the United States pushed U.S. MNEs to offshore employment. We complement this study by focusing on innovation outcomes in addition to labor inputs and by extending the analysis to a multicountry setting over a longer period of time. A study complementary to ours is the one by Prato (2021), which builds a structural model reflecting the U.S.-EU corridor, and finds that incentives for inventors to move from the U.S. to the EU increase innovation in the EU and reduce it in the U.S. in the short run. In our paper, we adopt a quasi-experimental approach relying on an array of positive and negative migration reforms adopted by countries across four continents and two decades, and we explore whether we can generalize the finding that one country's gain is another country's loss. Our analysis reveals that the United States is the country where mobility policies have the largest influence on the innovation of other nations, while reforms adopted by other major economies do not seem to generate

[9] Contributions in this literature include Kerr (2008); Agrawal, Kapur and McHale (2008); Breschi and Lissoni (2009); Hunt and Gauthier-Loiselle (2010); Kerr and Lincoln (2010); Agrawal et al. (2011); Moser, Voena and Waldinger (2014); Freeman and Huang (2015); Ganguli (2015); Bosetti, Cattaneo and Verdolini (2015); Choudhury (2016); Akcigit, Grigsby and Nicholas (2017); Breschi, Lissoni and Miguelez (2017); Bernstein et al. (2018); Miguélez (2018); Choudhury and Kim (2018); Doran and Yoon (2019); Burchardi et al. (2019); Miguelez and Noumedem Temgoua (2019); Beerli et al. (2021).

important spillovers. To the best of our knowledge, we are the first to explore whether policies facilitating human mobility have contributed to the rising share of global knowledge production among emerging markets, showing that they can account for about half of the change observed over the past 20 years.

Finally, our results also speak to the role MNE subsidiaries played in the knowledge-generating process and, thus, they underline the importance of their "absorptive capacity". This provides support for the knowledge-based view of the MNE: namely, that subsidiaries exist due to their ability to manage knowledge transfers in the face of international barriers to market transactions (e.g., Kogut and Zander, 1996; Caves, 1971; Cohen and Levinthal, 1990).[10]

In addition, we highlight data and methodology contributions. For this study, we built a novel database indexing 61 migration policy changes in 15 countries spanning the years 1990 to 2016, as described in Appendix C. Our dataset accounts for 80% of the global patents produced over the period, as recorded by the USPTO, and reports all the unilateral migration policies affecting the mobility of workers that were adopted in these countries. In terms of methods, we outline an empirical approach for dealing with the econometric difficulties imposed by high-frequency events that are clustered over time and for estimating causal effects given such a setting. This is important in our context because in some of the countries in our sample, the frequency of reforms is so high that several events of the same type occur in consecutive periods. This clustered nature of reforms limits estimation under classical event study methods, where the current practice is to consider only events that are, to some extent, isolated in time from other events. Instead, we put forward an adjustment to event-study methods that deals with the closely time-clustered nature of the reforms.[11]

The remainder of the paper is organized as follows: Section 2 covers the data constructed for estimation and Section 3 outlines the empirical strategy. Section 4 presents the results on the number of patents filed by subsidiaries, while Section 5 presents the results on the global dynamics

[10]This more broadly relates to the literature on the cost of knowledge transfers across borders (e.g., Giroud, 2013; Gumpert, 2018; Bahar, 2020).

[11]We go to lengths to discuss the robustness of this estimation approach in Appendix D.

of knowledge production. Section 6 concludes. The paper is accompanied by an online appendix with supplementary materials.

2 Data

2.1 Migration Reforms Dataset

The first data source is the information we compiled on dozens of migration reforms adopted by 15 countries over 26 years.[12] Our sample includes 61 work-related migration reforms enacted during the period going from 1990 to 2016 that either increased or decreased the expected flows of mobile inventors.[13] We select the countries in our sample with the aim of representing the largest innovation hubs and the main origins and destinations of inventor flows, as well as achieving a broad geographic coverage. Our final sample of countries represents 80% of all the patents produced from 1990 to 2016 that appear in the USPTO data, as well as 80% of all the GMIs. In addition, we cover countries located in Europe, East and South Asia, and North, Central, and South America.[14] Our final sample is reported in table 1. In the robustness analysis, we test that our results survive the exclusion of particular countries from the sample, to ensure that findings are not driven by our sample choices.

[12] These reforms were identified as part of a larger project to construct a systematic index of all unilateral policy reforms and governmental programs instituted across 15 countries and over more than a century that were anticipated to drive changes in the migration patterns of high-skilled immigrant workers. (We provide more details on this project in Appendix C).

[13] We focus on unilateral policy reforms adopted independently by countries and exclude regional agreements such as the European Union enlargement. We do this as an effort not to confound effects for firms in a given country with effects resulting from dynamics happening in other countries. As a robustness check, however, we present the coefficients obtained after controlling for the major trade and regional agreements signed over the period, including the subsequent waves of EU enlargement.

[14] In practice, to define the sample, we started with the 16 countries used by Branstetter, Fisman and Foley (2006), who study the impact of systematic reforms designed to strengthen and standardize intellectual property on MNEs' foreign direct investments from 1982 to 1999. The sample of Branstetter, Fisman and Foley (2006) includes Argentina, Brazil, Chile, Colombia, India, Japan, Korea, Mexico, Philippines, Portugal, Spain, Thailand, Turkey, Taiwan, and Venezuela. We depart from their list by adding four major countries that count more than 1% of inventors that are GMIs in the patent data (Canada, Germany, the United Kingdom, and the United States) and by dropping five countries from the Branstetter, Fisman and Foley (2006) sample that patent very little and have a share of GMIs among all inventors that is 0.1% or less (Argentina, Colombia, Thailand, Turkey, and Venezuela). See Appendix C for a detailed discussion on the selection of countries in the sample.

The work-related migration reforms in our data—which we detail fully in Appendix C—largely consist of changes in the visa application processes that either facilitate or harden skilled workers' access to a country (e.g., standardization of entry procedures, introduction of "point-based" systems selecting migrants with technical skill sets) or in changes in the benefits foreign workers receive after entering the country (e.g., allowing for access to health benefits and facilities). We categorize each reform as positive or negative depending on the expected effect on the flow of global mobile inventors. Some examples of reforms include:

- In 2010, South Korea implemented HuNet Korea, a three-way platform that standardized business-related migration processes and digitally matched three groups: high-skilled foreign workers searching for employment, companies seeking employees with technical skill sets, and the governmental system necessary for approving visa applications. This reform established a cohesive platform for long-term business-related migration into South Korea and it is, thus, coded as positive.
- In 2004, the United States reduced the cap of H1-B visas (the main channel through which American companies hire skilled foreign workers) from 195,000 to 65,000 visas per year, while declaring exemptions for the first 20,000 applicants with graduate degrees. Additional restrictions and regulations were enacted for L-1 visas, which govern intracompany short visits. Thus, this reform is coded as negative.

Table 1 summarizes the list of reforms by type included in the final sample.[15] The number of positive changes outweighs the negative ones by more than three times, which is in line with the general observation that international migration flows have been growing over the past 20 years (Kerr et al., 2016). Some countries in our sample, such as Korea and Japan, experience numerous reforms that are temporally close to each other, which raises some challenges for the econometric strategy. In the next section, we propose a novel solution to cope with the high frequency of some

[15] Appendix table C12 further classifies each reform into permanent versus temporary (depending on whether they affect stays of more or less than one year), volume versus rights, and major versus minor. These distinctions are used in the heterogeneity analysis. One policy includes both positive and negative elements and is, thus, double counted in this table. It concerns the United Kingdom in 2006. For more details, see Appendix C.

of these events.

Table 1: List of migration reforms by country

Country	Positive Migration Reforms	Negative Migration Reforms
Brazil	2014	-
Canada	-	2002
Chile	2005	-
China	1994, 2004, 2008, 2013	1996
Germany	2000, 2005, 2012, 2016	2004
Spain	1996, 2003, 2009	-
United Kingdom	2006	1996, 2006
India	2005, 2016	
Japan	1992, 1993, 2010, 2012, 2014, 2015	-
Korea	1991, 1992, 1993, 1994, 1995, 1996, 1998, 1999, 2002, 2004, 2007, 2009, 2010	-
Mexico	2010, 2011, 2014	2012
Philippines	1996, 2002, 2013	2009, 2012, 2015
Portugal	2001, 2012	2003
Taiwan	2014, 2015	1992
United States	1990, 1998, 2000, 2015	2004, 2009
Total N. of reforms	49	13

This table details the year of implementation for each of the 61 reforms enacted over the period of interest. The reform introduced in the United Kingdom in 2006 has both positive and negative elements and is, thus, double counted in this table.

2.2 Patent Data

Our patent data comes from PatentsView, a data visualization tool maintained by the Office of the Chief Economist at the USPTO.[16] Among its many offerings, the open data platform contains the universe of patents *granted* by the USPTO from 1976 to present, which includes about 15 million patents filed by about 6 million inventors and assigned to close to 500,000 firms.[17] This

[16]The tool is a joint effort by the USPTO, American Institutes for Research (AIR), University of Massachusetts Amherst, New York University, University of California, Berkeley, Twin Arch Technologies, and Periscopic.

[17]The universe of USPTO patents might not include all the patents filed in other jurisdictions. Yet, the USPTO is the largest repository of patents, and the consensus is that the most important innovations tend to be filed

dataset has some important characteristics that make it stand out. In particular, PatentsView uses complex algorithms to disambiguate the names of inventors and of assignees over time, resulting in a unique identifier for both inventors and MNEs (see Monath, Jones and Madhavan (2020) for more information on the disambiguation methods).[18] The data further includes the inventors' locations at the time of each patent filing (required by law). This, combined with the unique individual identifier, allows us to track inventors' mobility across borders. The inventors' locations, alongside the unique identifier of the firm to which the patent is assigned to (i.e., the assignee), also allows us to identify the location of MNE subsidiaries.[19] Since our goal is to capture the point of time when the innovation happens, and consistent with the standards in this literature, we define the patent date as the earliest between the application date and the priority date.[20] Our final sample is restricted to MNEs with patent production in at least two of the 15 countries for which we gathered reform information, given that the fixed effects included in our identification strategy drop MNEs patenting in only one country.

To test whether inventors' mobility reacts to reforms, we compute the number of GMIs observed in subsidiaries each year. We identify inventors as GMIs starting from the point when they are observed patenting in a country different from the one of their first appearance.[21] Our primary outcome measure is the count of all patents filed by an MNE subsidiary in a given year. We

to the USPTO in addition to all other patent offices (hence, it is the largest one). As such, we do believe that by concentrating on the USPTO (which allows us to follow inventors across time and space unlike with other datasets), we are capturing the fundamental patterns in innovation.

[18]Extensive prior work describes both the USPTO data and assignee disambiguation efforts (see Hall, Jaffe and Trajtenberg 2001; Jaffe 2017; Balsmeier et al. 2018) as well as the role of patent data as an indicator of innovation (Trajtenberg, 1990; Hall, Jaffe and Trajtenberg, 2001).

[19]The most common practice is that an inventor reports the address of his or her office at the moment of filing the patent. This information is, thus, useful both to determine the countries where the MNE has offices around the world and to measure inventor mobility across borders. It is important to note that in this data we observe only subsidiaries and individuals when they patent. Therefore, we have no record of the location of a subsidiary if there are no patents assigned to it in a given year. To ensure that attrition in the data is not biasing our results, we perform a robustness test where we impute subsidiaries in years when they are missing, and we assign to them zero patents and zero GMIs. Results remain consistent (see Section 4.2).

[20]For patents that have been filed only in the USPTO, the application and priority dates should be the same. For patents that have been filed in another patent office (such as the European Patent Office or the Japanese Patent Office, for instance), the priority date (often recorded in the patent record) refers to the date in which the patent was filed for the first time in any patent office.

[21]This is consistent with the work presented by Bahar et al. (2021). We further tested the robustness of our findings to using different measures of GMIs (e.g., an inventor being considered a GMI only during the first year after his or her cross-border moved is observed), and we find our results to hold. These results are available upon request.

further distinguish between two different types of patents: global collaborative patents (GCPs), which are patents filed by teams of inventors located in at least two different countries at the time of the invention,[22] and domestic patents, which are filed by teams of inventors residing entirely in the same country. Finally, in some analyses we further distinguish between patents filed by teams with at least one GMI and patents filed by teams composed entirely by never-movers, and we construct different indicators of patent quality following the definitions of the OECD (Squicciarini, Dernis and Criscuolo, 2013).[23]

2.3 Final Sample

When the reforms are combined with the patent measures, the data consists of a finalized panel at the MNE-country-year level that is balanced within countries and which consists of 297,919 observations indexing 28,443 MNEs with a total 70,624 subsidiaries across the 26 years observed. We present descriptive statistics in table 2. A few observations are of note. First, GCPs and patenting by GMIs represent the minority of patenting by the MNEs, since domestic patents represent, on average, approximately 88% of patent production by MNE subsidiaries. The summary statistics show that patents filed by teams including at least one GMI represent about 21% of MNE patenting activity; the rest are filed by teams of never-movers. GMIs are more prevalent in the production of GCPs, since more than 50% of these international collaborations are filed by teams with at least one GMI. In a given year, the average subsidiary in the sample produces 13 patents. The distribution is, however, highly skewed: The median subsidiary files only two patents per year, while the one at the 95th percentile files 40 patents and the maximum reaches more than 7,000. On average, each subsidiary counts 1.4 mobile inventors, which amounts to 13% of their total number of inventors.

[22]Kerr and Kerr (2018) first described the concept of GCP, and we draw on that paper as our motivation for using GCPs to measure globalized innovation processes. While defined in that study as an MNE patent with a U.S. and an international invention team, we define a GCP as any patent with a geographic footprint crossing an international border.

[23]We end up with five distinct proxies for quality, which we aggregate for each MNE subsidiary per year: i) patent generality; ii) patent originality; iii) patent radicalness; iv) share of patents considered breakthrough; and (e) number of citations per patent. We use these measures to present results for the impact of migration reforms on all five innovation quality measures.

Table 2: Summary statistics of main outcomes

	Full sample	
VARIABLES	mean	(sd)
N. of patents	12.9	(86.4)
N. of GCP	1.5	(8.9)
N. of domestic patents	11.3	(80.9)
Patents by teams with at least one migrant inventor		
N. of patents	2.8	(23.5)
N. of GCP	0.8	(5.5)
N. of domestic patents	1.9	(19.7)
Patents by teams without any migrant inventor		
N. of patents	10.1	(67.6)
N. of GCP	0.7	(3.8)
N. of domestic patents	9.4	(65.5)
Quality of patents		
Average patent generality	0.51	(0.22)
Average patent originality	0.77	(0.16)
Average patent radicalness	0.39	(0.22)
Share of breakthrough patents	0.01	(0.08)
N. of citations per patent	14.52	(37.08)
Migrant inventors		
N. of migrant inventors	1.4	(9.3)
Share of migrant inventors	0.13	(0.27)
N. observations	297,919	

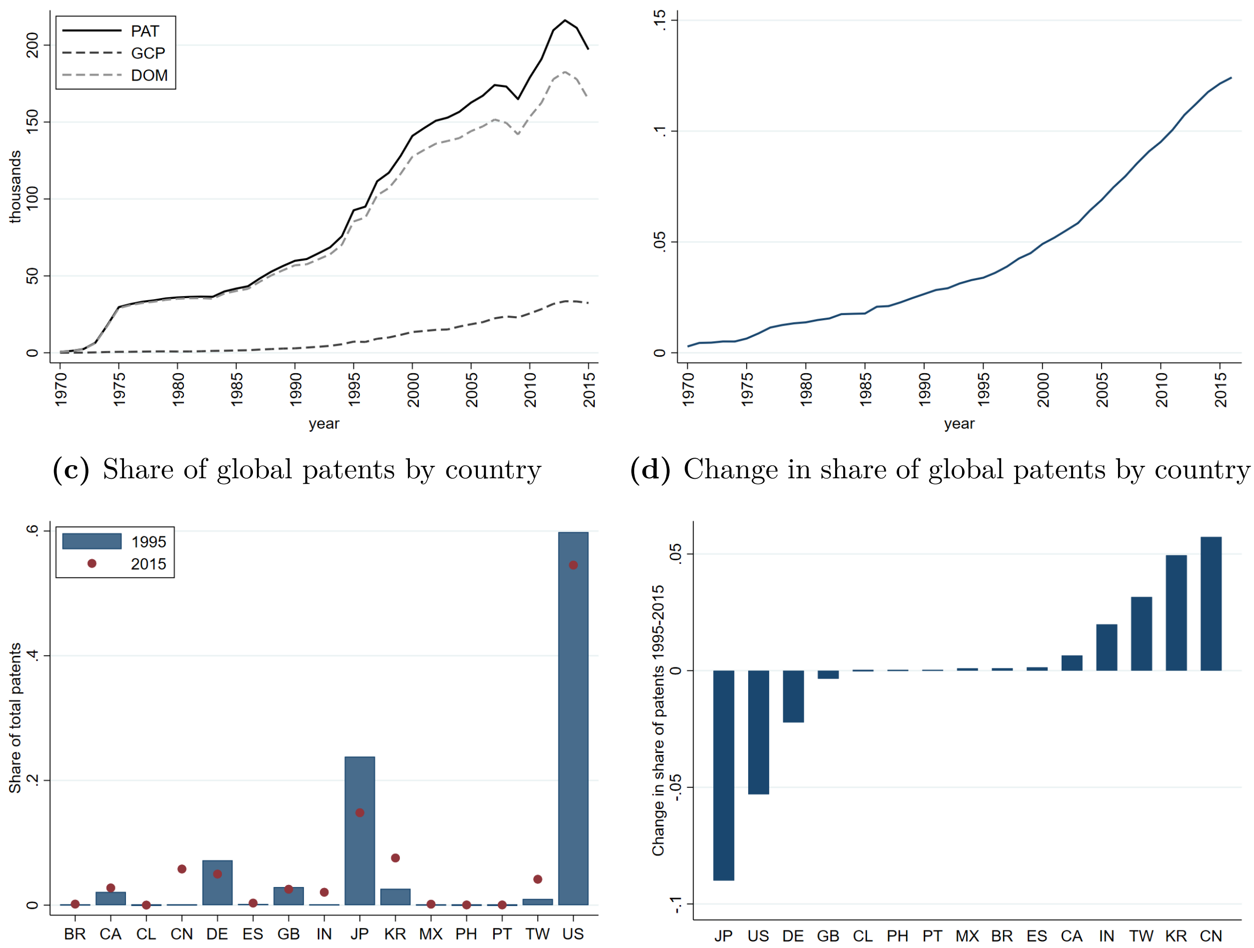
Summary statistics computed over the sample of subsidiaries, identified by MNE x country pair, in the sample spanning from 1990 to 2016.

Appendix table A1 displays the same summary statistics for each of the countries in the sample. There is substantial geographical heterogeneity, with Western countries (Germany, the United Kingdom, and the United States) showing the largest concentration of MNEs, followed by Asian countries (e.g., Japan, China, and Taiwan). Additionally, certain countries produce global collaborative patents at greater rates than they do domestic patents—and at significantly higher rates than those found in Kerr and Kerr (2018).[24] This underlines wide heterogeneity in knowledge production strategies and implies that similar policies might have very different effects depending

[24] They measure collaborative patenting rates among U.S. MNEs and find a rate approximately 30% to 55%.

on the region.

Figure 1: Global trends in patenting and migration



(a) Number of patents

(b) Share of GMIs

(c) Share of global patents by country

(d) Change in share of global patents by country

Panel (a) shows the evolution of the total number of patents reported in the USPTO data (solid line), as well as the breakdown between domestic patents and GCPs. Panel (b) shows the evolution of the share of global migrant inventors out of the total population of inventors. An inventor is considered a GMI if he or she is observed patenting in a different country with respect to the first country of appearance in the data. Panel (c) shows the share of total patents in the sample filed by each country in 1995 and 2015, and Panel (d) shows the change in that share.

Patenting rates rose significantly post-1980 (an increase that is well documented in Kortum and Lerner 1999), and domestic patents rose substantially more than GCPs, as shown in figure 1a. At the end of the period, there is a slight decline due to rightward censoring, explained by the time lag existing between patent filing and approval. In fact, to avoid our results being affected by this censoring, we limit our sample period to 2016, though this has no qualitative impact on our findings. Beyond the observed growth in the number of patents registered in the USPTO data, we also observe significant growth in the share of inventors that move internationally, going from about 1% in the 1970s to 12% in 2015 (figure 1b), consistent with Bahar et al. (2021). We further observe a substantial shift in the distribution of patents across countries over the period (figures 1c and 1d). In 1995, the United States filed 60% of all patents in our sample, followed by Japan (25%) and Germany (7%). Emerging markets such as China, India, and Taiwan accounted for a negligible share of global patents. In 2015, the United States and Japan remain the leaders of innovation activities, but their global patent shares is significantly lower, while China, Korea, Taiwan, and India start playing an important role in global knowledge production. Over this period, there was, thus, an important shift in the geography of innovation away from developed countries (such as the U.S., Germany, and Japan) toward emerging markets. Our analysis explores whether policies affecting human mobility had a role in explaining such a shift.

3 Empirical Strategy

Our empirical strategy applies an event study framework in which the identification relies on the assumption that migration policy reforms—our "treatment" events—are exogenous to the MNE subsidiaries within the enacting country. To ensure exogeneity, we exploit the fact that although assignment of reform events is potentially endogenous to country-level characteristics and trends, subsidiaries within the same country vary ex ante in the extent to which they are capable of reacting to a given policy change. Since reforms impact MNEs by easing or complicating their efforts to transfer human capital across countries, we posit that subsidiaries of MNEs with historically high labor mobility, before the policy is announced, are likely to respond more to changes in migration incentives. Thus, our measure of exposure is computed as the ratio between the number of mobile inventors that patented in all the other subsidiaries of the MNE (except for the one where the reform takes place) scaled by the total number of inventors in all the other subsidiaries of the MNE. For this measure, we consider inventor mobility happening across countries within the same MNE. The idea is that firms that have invested in large HR departments and that have strong cultures of labor mobility will react more to the changing regulations. This ratio is computed over a moving window of five years prior to each observation and captures the probability that any given inventor would move within that company.[25] Formally, the exposure measure is defined by the following formula:

$$exp_{fct} = \frac{\sum\limits_{c',t'} MobInv_{fc't'}}{\sum\limits_{c't'} Inv_{fc't'}},$$

where $c' \in C|\{c\}$ and where $t' \in (t-5, ..., t-1)$. To ease the interpretation of the results, the exposure measure exp_{fct} is standardized to have a mean of 0 and a standard deviation of 1. Given that it is computed using the mobility rate observed in all other countries, we expect it to be exogenous to innovation trends observed around the reform. We further test the robustness of results to an exposure measure that applies the same formula but uses the moving window spanning 5 to 10 years prior to each observation. Finally, we show through placebo tests that our exposure measure is not correlated with different innovation trends at times with no reforms.

A second estimation challenge resides in the presence of repeated reforms that are highly clustered in time. Standard econometric practice suggests isolating those observations "treated" only once or estimating treatment effects only in short-run windows that do not include any repeated treatment events. However, neither technique is well suited to the current setting since reform events are enacted repeatedly within the large majority of our countries (the only exceptions being Brazil, Canada, Chile, and India). To resolve this issue, we introduce a novel empirical approach to estimating treatment effects given repeated events clustered in time. Specifically, we construct count measures for positive and negative reforms ($PRef_{ct}$ and $NRef_{ct}$) that vary dynamically over time, changing in level as treatment events accumulate.[26] Appendix D reports simulations that validate the estimator, discusses the additional assumptions it imposes on causal inference, and outlines a generalized version of the estimator that allows the treatment effect to vary conditional

[25]We assign an exposure of zero to subsidiaries belonging to MNEs that file patents only by teams of never-movers in all the other countries over the window of interest. We also assign an exposure of zero to MNEs that are not observed patenting at all over the window of interest.

[26]This term is akin to employing an "intensity of treatment" variable in difference-in-differences, in which treatment obtains multiple levels or reflects an observation's propensity to treatment (similar to specifications employed in, e.g., Duflo 2001; Acemoglu, Autor and Lyle 2004), but where the intensity of treatment varies with time.

on the level of consecutive events.[27]

As a result, our main analysis is based on the following model:

$$Y_{fct} = \beta_0 + \beta_1 exp_{fct} + \beta_2(exp_{fct} \times PRef_{ct}) + \beta_3(Exp_{fct} \times NRef_{ct}) + \beta_4 X_{fct} + \gamma_{ct} + \delta_{ft} + \epsilon_{fct}, \quad (1)$$

where Y_{fct} represents the innovation output in year t of an MNE subsidiary, defined as the combination of MNE firm f and country c. Given that the distribution of the number of patents filed by a subsidiary in a given year is very skewed, we run the regressions on inverse hyperbolic sine (arcsinh) transformed outcomes, such that the coefficients can be interpreted in terms of growth rates, and the variables are defined in zero (Card et al., 2020). The output Y_{fct} is a function of the exposure measure (exp_{fct}), and of the interaction of the latter with positive ($PRef_{ct}$) and negative ($NRef_{ct}$) cumulative counts of reforms enacted by year t in the subsidiary country c. We further condition on fixed effects at the levels of MNE-year (δ_{ft}) and country-year (γ_{ct}), in order to identify the effects of reforms independent of MNE and country trends. We do not add subsidiary-level fixed effects because it would absorb 92% of the variation in output, making it too demanding given that we have very few observations across time.[28] However, we control for possible pre-trends in subsidiary productivity by including a control for subsidiary-level initial number of patents interacted by year fixed effects (X_{fct}). The model is estimated using OLS, and standard errors are clustered at the subsidiary level. The key coefficients β_2 and β_3 can be interpreted as the marginal effect of one additional positive/negative reform on innovation output.[29]

[27] Appendix B further tests the validity of the main assumptions behind this estimator. We find that using our dependent variable as a count of reforms is a good approximation to the average effect of each reform taken separately. However, a caveat of this approach is that it is too complex to apply the most recent corrections for heterogeneous and time-varying effects in staggered event study designs (Borusyak and Jaravel, 2017; Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021; De Chaisemartin and D'Haultfoeuille, 2022).

[28] Adding them results in some qualitatively similar point estimates but much less precise, as expected

[29] Appendix D reports simulations that validate the estimator using cumulative count events, discusses the additional assumptions it imposes on causal inference, and outlines a generalized version of the estimator that allows the treatment effect to vary conditional on the level of consecutive events. Appendix B tests the validity of the main assumptions behind this estimator.

The counterfactual modeled by this approach compares the change in innovation of high-exposure subsidiaries observed after a reform with the same change observed among low-exposure subsidiaries in the same country, while netting out changes attributable to MNE-specific trends (by including MNE-by-year fixed effects) and to time trends explained by initial subsidiary productivity (by including initial level of patenting interacted with year fixed effects). It also compares subsidiaries of the same MNE located in countries with reforms at different times, netting out country-specific trends (by adding country-by-year fixed effects). This identification strategy relies on the assumption that the timing of the reform and the ex ante exposure of the subsidiary, combined, are exogenous to the subsidiary's future patenting activity. We believe these are reasonable assumptions in our context, and we present several tests showing that exposure is not correlated with differential trends in patents in the absence of reforms.

One possible limitation of our approach is that when pooling reforms together, we are implicitly assuming they all carry the same weight or importance. As such, we also present in our main results an alternative specification that exploits the actual number of inventors moving after each reform by implementing a 2SLS estimation. In it, we use the reduced-form estimation reported in equation 1 as a first stage to predict the number of GMIs in a subsidiary, where the interactions between subsidiary exposure and reform counts are considered an exogenous instrument. In the second stage, we regress the predicted number of GMIs on the innovation outcomes to recover the elasticity of patents with respect to GMIs. By doing this, we are taking into account the fact that different reforms have different intensity.[30] The exclusion restriction relies on the assumption that the effect that migration reforms have on innovation is entirely mediated by their effect on the number of mobile inventors.

[30] In addition, in Section 4.3 we present results where we classify reforms as major or minor to further deal with this concern.

4 Effects on the Local Production of Knowledge

4.1 Main Results

Table 3 reports the results of the reduced-form approach on the number of GMIs observed in a given subsidiary (Column 1), on the total number of patents filed (Column 2), and on the breakdown count between global collaborative patents and domestic patents (Columns 3 and 4). Finally, it provides the IV estimates for the innovation outcomes and the corresponding Kleibergen-Paap F-statistics (Columns 5 to 7), for which Column 1 constitutes the first stage. Each regression includes all the fixed effects and controls reported in equation 1.

Results in Column 1 show that our migration reforms indeed explain movement of inventors. We find that each additional positive reform increases the number of GMIs observed in exposed subsidiaries by 1.9% (first row), while each additional negative reform decreases it by 6% (second row). We prefer to express our point estimates relative to the baseline effect of exposure (third row), which says that a subsidiary that has an exposure of one standard deviation above the mean counts about 20% more GMIs before any reform. As such, a positive migration reform corresponds to an increase of about one-tenth in the number of mobile inventors, whereas the average negative reform results in a drop of about one third relative to the magnitude of exposure alone. Negative reforms have, thus, on average, much stronger explanatory power on the international flows of inventors relative to positive ones.

Columns 2 to 4 present the effect of reforms on the innovation outcomes themselves. We find that each additional negative reform decreases by 26.6% the overall number of patents filed by exposed subsidiaries relative to baseline. When looking at the patent types, we find that this corresponds to a 19% drop in GCPs and a 24% drop in domestic patents (always relative to the effect of exposure taken alone). Positive reforms do not have a significant effect on the overall number of patents, but do explain an increase in the number of GCPs by 6.6% (significant at the 10% level). Given the heterogeneity in types of reforms, we cannot know a priori whether the stronger effects of negative policies that we find are due to them being of higher intensity or due to them having a larger impact at comparable intensity. In Section 4.3, we dig deeper into this question to tease out which mechanisms explain this large heterogeneity in magnitudes.

Table 3: Main results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	N. GMIs (asinh)	N. Patents (asinh)	N. GCPs (asinh)	N. Domestic patents (asinh)	N. Patents (asinh)	N. GCPs (asinh)	N. Domestic patents (asinh)
VARIABLES	OLS	OLS	OLS	OLS	2SLS	2SLS	2SLS
Exposure x positive ref.	0.0194***	0.0138	0.00680*	0.0125			
	(0.00689)	(0.00882)	(0.00348)	(0.0102)			
Exposure x negative ref.	-0.0586***	-0.141***	-0.0198***	-0.165***			
	(0.0108)	(0.0140)	(0.00601)	(0.0168)			
Exposure	0.200***	0.531***	0.103***	0.683***			
	(0.0181)	(0.0244)	(0.0102)	(0.0291)			
N. GMIs (asinh)					1.823***	0.341***	2.071***
					(0.164)	(0.0586)	(0.193)
Observations	166,360	166,360	166,360	166,360	166,360	166,360	166,360
R-squared	0.510	0.544	0.670	0.525	0.306	0.356	0.326
K-P F statistic					14.98	14.98	14.98

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Column (1) reports the first stage effect on the number of GMIs, columns (2) to (4) show the reduced form results of reforms on patenting, and columns (5) to (7) show the 2SLS results of the effect of GMIs on patenting. Standard errors clustered at the subsidiary level. Initial N. patents in the subsidiary interacted with year dummies, MNE x year fixed effects and country x year fixed effects included in all regressions. Period of analysis: 1990-2016. Continuous exposure to the reforms is computed as the mobility rate of inventors observed within all the other subsidiaries of the MNE over the preceding 5 years.

The 2SLS results make no assumption about the intensity of each reform, but use the number of GMIs as the treatment instead, instrumented by the effect of reforms (with the first stage presented in Column 1). The results reveal that having 1% more GMIs in the subsidiary increases the number of patents filed by 1.8%, the number of GCPs by 0.3%, and the number of domestic patents by 2%. These elasticities are large, revealing the importance of attracting talent for companies to boost their innovation capacity.

4.2 Robustness Tests

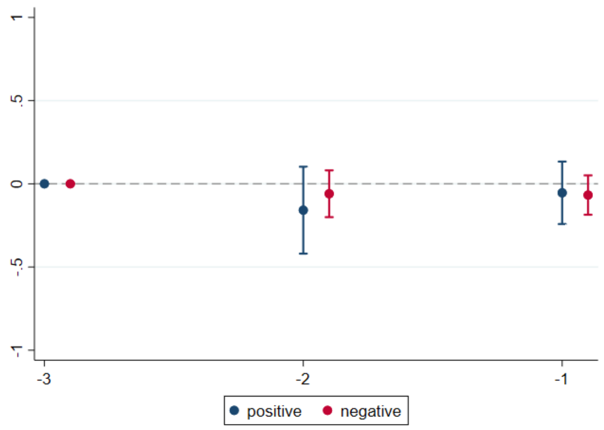
Validity of the identification assumptions. The cardinal assumption of difference-in-differences estimations is the common trend hypothesis. Namely, it supposes that the treated group would have evolved following the same trend as the control group in the absence of the treatment event. In our context, this assumption supposes that subsidiaries with different levels of exposure to the reform would have shown similar trends in GMIs and patenting in the absence of the reforms.

While this hypothesis is untestable, we can show that subsidiary exposure was not correlated with differential trends before the introduction of the first policy. Figure 2 reports the coefficients obtained after interacting the exposure measure with dummies for the three years preceding the first reform in each country of our sample. $T-3$ is normalized to zero, and we run regressions separately for the period preceding positive reforms and the period preceding negative ones. Results reveal pre-trends in neither GMI growth nor in patent growth (figures A1a and A1b test pre-trends for GCPs and domestic patents taken separately).

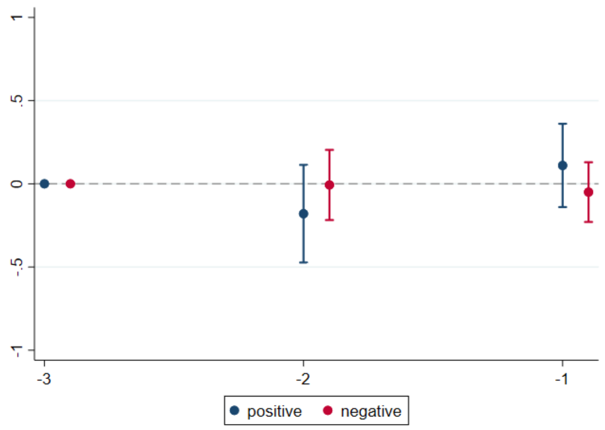
In order to get a sense of the dynamic effects at play, it is common practice in this type of graph to also show the coefficients associated with the years following the reform. In our context, given the presence of subsequent reforms within the same country that are sometimes clustered in time, we have to adopt a more complex strategy to show the dynamic effects, making use of Monte Carlo simulations. The latter are presented in Appendix B, together with additional tests of our econometric approach.

Figure 2: Test for pre-trends

(a) N. of GMIs (asinh)



(b) N. of Patents (asinh)

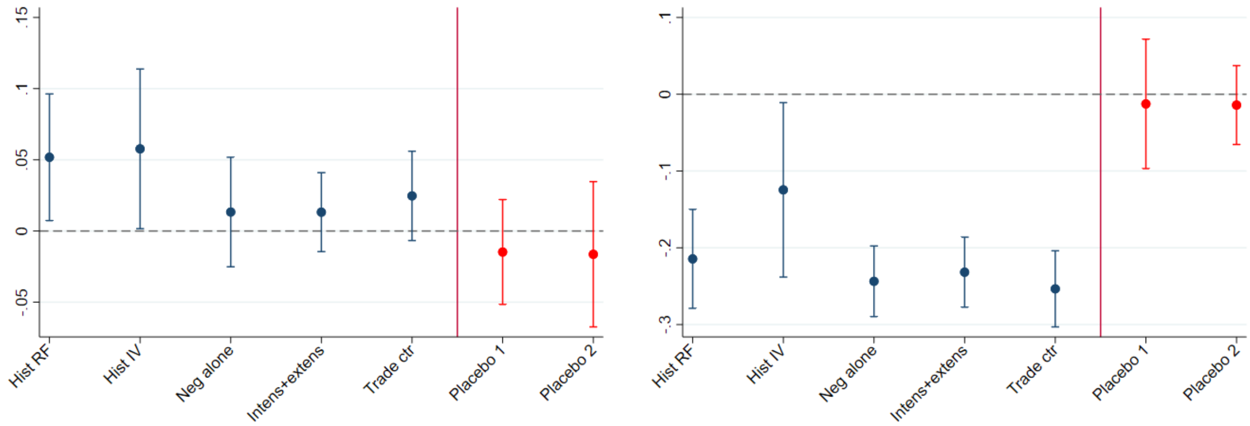


These graphs plot the dynamic effects obtained by interacting the exposure measure with dummies for the 3 years preceding the first reform in each country. Time t-3 is normalized to zero. The model is estimated separately for positive and negative reforms. The bars represent the 95% confidence intervals.

Figure 3 presents a series of additional robustness tests for the reduced-form analysis on the number of patents, reporting in separate graphs the coefficient associated with positive reforms and the one associated with negative reforms. Appendix figure A2 does the same for the regressions on the number of GMIs, and Appendix figure A3 shows the applicable robustness tests on the IV coefficient. Each dot corresponds to the coefficient obtained from a separate regression, with its associated confidence interval. To ease the interpretation of the coefficients, they are always rescaled by the beta coefficient obtained on exposure alone. The blue dots test the robustness of the main estimates, while the red ones introduce two separate placebo tests.

Figure 3: Robustness tests on N. of patents (asinh)

(a) Effect of positive reforms **(b)** Effect of negative reforms



Each dot represents the result obtained from a separate regression, while the vertical line reports the 95% confidence interval. To ease interpretation the coefficients are rescaled by $\beta[Exposure]$, such that the vertical axes can be read as growth rates relative to exposure alone. The coefficients in blue concern regressions with slightly modified samples or methodology, while the ones in red are two distinct placebo tests.

First, we test that results are robust to introducing an historic measure of exposure computed on the moving window spanning from $t-6$ to $t-10$ relative to each observation, instead of from $t-1$ to $t-5$ as is done in the main analysis. The first dot from the left in each graph shows the coefficient obtained from using the historic measure of exposure, while the second dot shows the result obtained when the current measure of exposure is instrumented by the historic one.[31] The third dot tests that the results hold when we estimate the effect of negative and positive reforms in separate regressions. Here, the 2SLS results are not significant when only positive reforms are used because the instrument becomes weak according to conventional thresholds.

By construction, in our data, we observe only subsidiaries that file at least one patent in a given

[31] This second test is applicable only for the reduced-form coefficients presented in figures 3 and A2, and not for the IV coefficient.

year. Consequently, our estimates on the total number of patents have to be interpreted as the effect on the intensive margin: Reforms affect the quantity of inventors that move across borders while continuing to patent and the amount of patents filed among subsidiaries that do innovate. In order to explore whether attrition in the sample is affecting our results, we input subsidiaries in the years when they do not patent if the MNE is observed patenting in other countries. For these observations, all the patent counts are set to zero. We then estimate the effect combining the intensive and the extensive margins by applying the same model to the new data. Given that our outcomes are modified using the arcsinh transformation, they are defined in zero. The fourth dot from the left in figure 3 presents the coefficients obtained after controlling for attrition.

In the main analysis, we decided to focus on unilateral reforms taken by individual countries that directly target the migration of workers. One might wonder whether our reforms are confounded with the signature of bilateral or multilateral trade agreements or by the EU enlargement that took place over the period. We borrow the dataset Gurevich and Herman (2018) created to identify all the major changes in trade agreements concerning our 15 countries during the period of interest,[32] and we combine them with indicators for each major EU enlargement episode, which are attributed as events for Germany, Portugal, Spain, and the United Kingdom (list reported in Appendix table A3). We then use the list combining trade and EU enlargement events to construct a cumulative count measure, which we interact with subsidiary exposure and introduce in the main regression as an additional control. The coefficients obtained are reported in the fifth dot from the left in figure 3.

Finally, the last two dots of figure 3, which are reported in red, perform two placebo tests to ensure that our measure of exposure is not correlated with differential trends in patenting that are unrelated to the reforms. In the first placebo test, we randomly assign 49 positive and 13 negative fictitious reforms over the sample of 15 countries and 26 years (following the actual

[32]We define events whenever a country signs for the first time a new type of agreement over the period, including i) economic integration agreement, ii) customs union, iii) free trade agreement, iv) partial scope agreement, v) preferential trade agreement, vi) entrance in the WTO. This results in 16 events in our sample, which are detailed in Appendix table A2. We also test whether results are robust to identify as an event every time a country signs an additional agreement, even when it is not the first one of that type. In this case, we obtain 192 events and find our results are robust to this approach. Results of this second approach are available upon request.

number and types of reforms), and then we run our main specification on this modified dataset. We repeat the operation over 1,000 replications, and we report the mean of the coefficients of interest as well as the bootstrapped standard errors. In the second placebo test, we do the same procedure, but we randomly assign 61 fictitious reforms to our country-year sample, randomly classifying them as positive or negative, therefore relaxing further the structure of the data by not imposing a fixed number of positive and negative events. Both of these exercises result in small and insignificant coefficients associated with positive and negative pseudo-reforms, while the exposure coefficient alone remains significantly positive and similar in magnitude to the one obtained in the main analysis. These placebos confirm that exposure alone is not associated with differential time trends if not interacted with the timing of actual reforms.

From this exercise, we conclude that the coefficient associated with negative reforms is robust to measuring exposure further back in time, to including only negative reforms in the regression, to accounting for the extensive margin of the effect, and to controlling for trade agreements and the EU enlargement, while our exposure measure is not correlated with differential trends on outcomes in periods without any reforms. The IV coefficient is also broadly consistent across all robustness tests, except when we use only positive reforms (because the instrument becomes weak).

Selection of the sample. Further, we test the sensitivity of our results to excluding one-by-one the major countries from the sample, as well as from excluding one-by-one the three main regions.[33] Results are reported in Appendix figures A4, A5, and A6 for the reduced-form results on number of patents, number of GMIs, and the 2SLS results, respectively. The reduced-form effect of positive reforms on patenting becomes significant at the 10% level in some of the samples excluding one country, and it is larger when the U.S. is excluded. The effect of negative reforms is robust to excluding any of the countries from the sample, but the standard errors become wider in the sample without the U.S. Consistently, we see from the regional heterogeneity analysis

[33]The countries with more than 5,000 observations in our sample are Canada, China, Germany, India, Japan, South Korea, Taiwan, the United Kingdom, and the United States. The three main regions are Asia, Europe, and North America.

that negative reforms are particularly detrimental in North America, while positive reforms are particularly beneficial in Asia. This is in line with evidence presented in Section 5, showing that emerging markets benefit more than others from positive migration reforms. The 2SLS regressions consistently show that GMIs increase patenting, no matter which country is excluded from the sample.

4.3 Heterogeneity and Mechanisms

A caveat we discussed above is that we cannot know a priori whether the stronger effect of negative reforms is driven by differences in reform intensity or asymmetric effects generated by reforms with similar intensity. In this section, we divide the sample of reforms by type and see whether the stronger effect of negative reforms is confirmed within a given type or whether it is driven by different type composition. We look at the effect of: i) permanent versus temporary reforms, defined based on whether they target immigration for more or less than one year; ii) volume versus rights reforms, defined based on whether the reform changes migration quotas or rather the rights that migrants enjoy once in the host country; and iii) major versus minor reforms, defined based on the intensity of the change. Appendix table C12 shows how each reform is classified across these three dimensions. Table 4 presents the results, where coefficients in the adjacent columns are estimated in the same regression (see numbering of columns to distinguish separate regressions).

We see that the effect of positive reforms remains insignificant across all types, while the effect of negative reforms remains highly significant across all types. This result suggests that the larger effect of negative reforms is not driven by different reform intensities, as captured by our types, but by asymmetric effects within a given intensity. Further, we can note that negative permanent reforms have a stronger impact than temporary ones, that changes in quotas have a stronger impact than changes in rights, and that major reforms have stronger impacts than minor ones. These findings go in the expected direction and add robustness to our estimation strategy.

We conducted a variety of other tests to explore the mechanisms behind the asymmetry of effect

Table 4: Effect on patents by reform type

	(1)		(2)		(3)	
			N. Patents (asinh)			
	Permanent	Temporary	Volume	Rights	Major	Minor
VARIABLES	OLS	OLS	OLS	OLS	OLS	OLS
Exposure x positive ref.	0.00638	0.0158	0.0120	0.0162	0.0127	0.0174
	(0.00817)	(0.0163)	(0.0105)	(0.0224)	(0.0141)	(0.0181)
Exposure x negative ref.	-0.138***	-0.0818**	-0.134***	-0.0672**	-0.185***	-0.0936***
	(0.0139)	(0.0327)	(0.0146)	(0.0272)	(0.0273)	(0.0262)
Exposure	0.550***		0.522***		0.534***	
	(0.0252)		(0.0273)		(0.0252)	
Observations	166,360		166,360		166,360	
R-squared	0.544		0.544		0.544	

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Regression (1) includes interaction between the exposure measure and four count variables recording positive and negative permanent and temporary reforms. Regression (2) does the same for positive and negative volume and rights reforms, and Regression (3) for positive and negative major and minor reforms. Initial N. patents in the subsidiary interacted with year dummies, MNE x year fixed effects and country x year fixed effects included in all regressions. Period of analysis: 1990-2016. Continuous exposure to the reforms is computed as the mobility rate of inventors observed within all the other subsidiaries of the MNE over the preceding 5 years.

between positive and negative reforms; these are reported in Appendix A. In short, we find that the stronger effect of negative reforms is driven by the reaction of small firms, which profit less than large firms following an increase in access to cross-border mobility, but suffer significantly more from reforms restricting such access (see Table A4).[34] Finally, negative reforms not only decrease patents filed by teams involving GMIs, but also generate negative spillovers on teams of never-movers. Average patent quality, on the contrary, is not affected by our reforms.[35] These results confirm that the harm generated by restricting firms' access to talent is pervasive.

[34] In fact, in large MNEs, the effects of positive and negative reforms are symmetric.
[35] Table A5 explores the heterogeneous effect of reforms on patenting by teams that include or not GMIs. Table A6 reports the effect on five measures of patent quality: generality, originality, radicalness, breakthroughs, and number of citations.

5 Effects on the Global Production of Knowledge

5.1 Race for Talent: Identifying Global Spillovers

In this section, we go beyond the effect of mobility reforms for the countries that adopt them, and we leverage our multicountry setting to look at how reforms in one country affect patenting elsewhere. To do this, we add to our framework additional regressors for the count of positive and negative reforms that take place in another country ($PRef_{c't}$ and $NRef_{c't}$), interacted with the exposure measure, as follows:

$$Y_{fct} = \beta_0 + \beta_1 exp_{fct} + \beta_2(exp_{fct} \times PRef_{ct}) + \beta_3(Exp_{fct} \times NRef_{ct}) + \alpha_2(exp_{fct} \times PRef_{c't}) + \alpha_3(Exp_{fct} \times NRef_{c't}) + \beta_4 X_{fct} + \gamma_{ct} + \delta_{ft} + \epsilon_{fct}, \quad (2)$$

where c' includes each of the major countries in our sample, added one by one in separate regressions.[36] Results are reported in Appendix table A7, and the main coefficients of interest (α_2 and α_3 in equation 2) are summarized in figure 4. Table A7 shows that the effect of own positive and negative reforms (β_2 and β_3 in equation 2) remain unchanged regardless of the additional reforms added in c'. Figure 4 shows that the country with the most clear cut spillovers is the U.S.: Each reform discouraging migration the U.S. adopts increases patenting in other countries (+7%), while each reform encouraging migration the U.S. adopts decreases patenting in other countries (-7%). In comparison (based on the point estimates reported in Appendix table A7), a negative reform by the U.S. is equivalent to a third of the effect of a positive reform for the (non-U.S.) average country, everything else equal. We can also note that positive reforms in Taiwan contribute to decrease patenting elsewhere.[37] However, according to our results, negative reforms

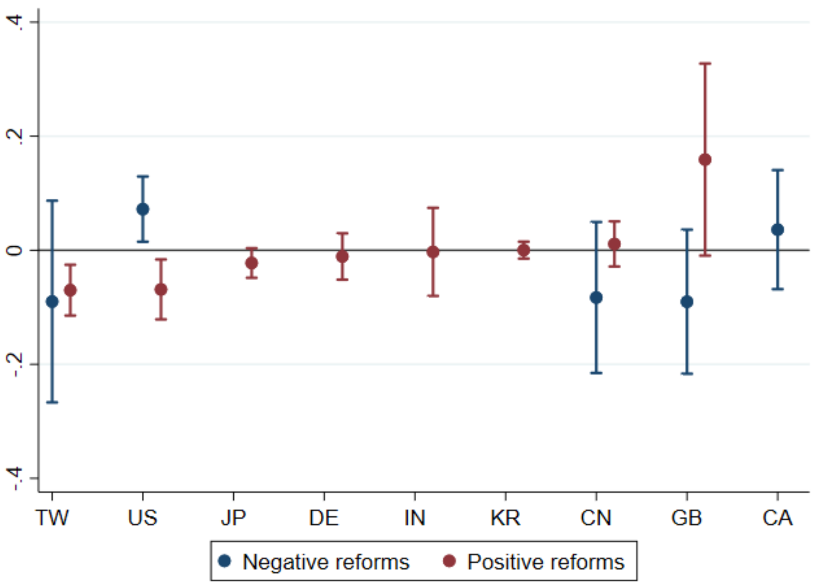
[36] The major countries are defined as those with more than 5,000 observations in our sample.

[37] Positive reforms in the U.K. increase patenting elsewhere, but only marginally significantly. It might well be driven by firms in other European countries benefiting from the flow to the continent (particularly since our data is pre-Brexit).

do not generate any international spillovers when adopted in countries other than the U.S.

These results reveal that there is indeed a global competition to attract talent. In particular, when it comes to the U.S., the leading economy in terms of innovation, changes in its migration policies have important consequences for the innovation of other countries. We see this result as a central part of this paper's contribution, as it shows that focusing on the local effects of mobility on innovation while not accounting for the dynamics of other countries misses part of the picture. This finding also complements the results of Glennon (2020) and Prato (2021) by showing that the United States is a special case when it comes to its ability to poach talent from other nations.

Figure 4: Spillover effects of reforms across countries



Each dot represents the result obtained from a separate regression adding to the main specification an additional interaction between exposure and positive and negative reforms taking place in another country, while the vertical line reports the 95% confidence interval. To ease interpretation the coefficients are rescaled by $\beta[Exposure]$, such that the vertical axes can be read as growth rates relative to exposure alone.

5.2 Shifts in the Geography of Knowledge Production

Finally, one of the most important questions we can answer in our global setting is whether human mobility explains shifts in the geography of global knowledge production over time. Figure 1d shows that during our period of interest, emerging markets such as China, India, Korea, and

Taiwan increased drastically their share of total patent production, at the expenses of advanced countries such as the United States, Japan, and Germany. We investigate the role played by mobility policies by estimating our main model on the share of total yearly patents filed by each subsidiary—a measure of global innovation share—and by evaluating the heterogeneity of the effect across countries with initially high and low shares of global patent production. We measure the initial share of global innovation by computing the total number of patents filed from 1985 to 1990 by each country in our data as a share of the total. The United States, Japan, and Germany are the countries with (by far) the highest initial shares of global patents, and they account for 67% of our sample. We treat all the other countries in our dataset as "low initial share." We then reestimate our main specification by adding a triple interaction as follows:

$$\begin{aligned} Y_{fct} = \beta_0 + \beta_1 exp_{fct} + \beta_2(exp_{fct} \times PRef_{ct}) + \beta_3(Exp_{fct} \times NRef_{ct}) + \beta_4(exp_{fct} \times LIS_c) \\ + \beta_5(exp_{fct} \times LIS_c \times PRef_{ct}) + \beta_6(exp_{fct} \times LIS_c \times NRef_{ct}) + \gamma_{ct} + \delta_{ft} + \epsilon_{fct}, \quad (3) \end{aligned}$$

where Y_{fct} captures the share of total patents filed in year t across all countries in the sample coming from subsidiary f in country c; LIS_c is a binary indicator identifying countries with low initial shares in global patent production. Appendix table A8 reports the results from estimating the baseline model reported in equation 1 as well as the triple interactions reported in equation 3. Column (1) of table A8 shows that positive reforms do not significantly impact the share of total patents filed by a subsidiary, but negative reforms do decrease it significantly. We find similar results for GCPs and domestic patents when considered separately (columns (3) and (5)). Interestingly, results are highly heterogeneous across the initial share of innovation. Countries that counted very little in global knowledge production at the beginning of the period gain significantly more following positive migration reforms, while the initial leaders in knowledge production appear to lose more following negative migration reforms, even if the difference is not significant. This result highlights how policies encouraging inventor mobility effectively helped emerging markets gain importance in the geography of global innovation. We observe these patterns once again for both GCPs and domestic patents (columns (4) and (6)).

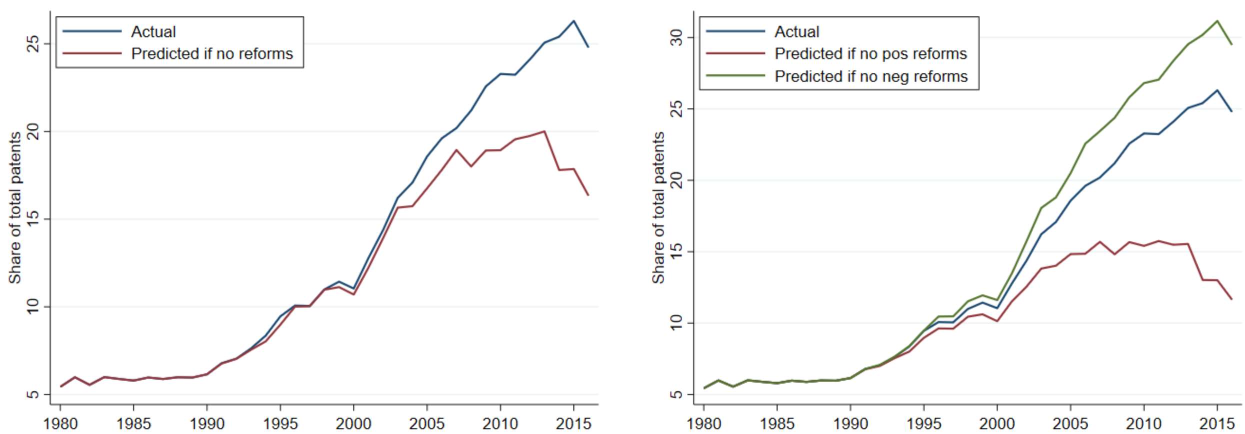
To get a sense of the economic significance of these effects, we compute some simple back-of-the-envelope calculations. We want to determine how much of the observed growth in the share of patents filed by emerging markets is explained by migration policies. We use our triple interaction model to predict the effect of positive and negative reforms on the share of global patents filed by each subsidiary f located in a country with low initial shares. We then use the prediction to calculate the total effect of reforms on the share of patents filed by each country c within the low initial share group in year t as follows:

$$\left(\frac{P\hat{A}T_{ct}}{PAT_t}\right) = \sum_{f=1}^{F} exp_{fct}\Big((\beta_2 + \beta_5)PRef_{ct} + (\beta_3 + \beta_6)NRef_{ct}\Big). \tag{4}$$

Finally, we compute the predicted aggregate trends in the geography of innovation in the absence of migration reforms by subtracting $\frac{P\hat{A}T_{ct}}{PAT_t}$ from the actual share observed in each country $\frac{PAT_{ct}}{PAT_t}$ and aggregating it over all countries with low initial shares.

Figure 5: Predicted aggregate trends observed in emerging markets

(a) Effect of all reforms **(b)** Effect of positive and negative reforms



The actual outcomes are the share of total patents observed in countries with low initial shares across the period of interest (includes all countries except the U.S., Japan, and Germany). We obtain the predicted outcomes by subtracting the predicted effect of positive and negative migration reforms from the actual outcomes.

Figure 5a shows that countries with low shares of patents at the beginning of the period would have grown only from roughly 5% to 19% of total innovation in the absence of migration reforms, while the actual change that occurred over the period brought them to 25% of total innovation. Figure 5b further distinguishes between the predicted outcome in absence of positive migration reforms and in absence of negative migration reforms, showing that positive reforms have substantially helped these countries become leading inventors. If emerging markets would not have adopted any negative migration reform, they would have reached up to 30% of patents filed by 2015. On the contrary, if they would have adopted only negative migration reforms (but no positive ones), they would have remained at 12% of total knowledge production. These results strongly suggest that policies favoring human mobility have helped emerging markets in their global innovation race. Migration reforms are, thus, crucial elements in helping us understand global trends in the geography of innovation over the past decades. Appendix figure A7 disaggregates the comparison between actual and predicted trends by country, showing that positive migration reforms generated particularly large boosts for China and Korea.

6 Concluding Remarks

The global patterns of knowledge production are changing. The impressive rise of China and India as sources of the production of global innovation in the past two decades has often been attributed to MNEs shifting their patenting activity toward these countries. MNEs' innovative potential is increasingly recognized to rely on the knowledge and absorptive capacity of its local subsidiaries.

This paper presents robust evidence for an additional driver of this process: the cross-border mobility of inventors. Specifically, we investigate whether and to what extent subsidiary-level investments in innovation change following migration reforms that either ease or reinforce barriers to immigration into the country. We find that pro-business migration reforms significantly increase MNE innovation within a country, especially in terms of GCPs, while reforms that discourage migration lead to significant declines in both domestic patents and GCPs. The effect of positive reforms is driven by teams involving GMIs; while the effect of negative reforms is driven by a change in innovation produced by teams that directly involve GMIs as well as by domestic teams composed entirely of never-movers.

Yet, perhaps the central contribution of our study is to show that inventor mobility plays an important role, too, in explaining the dynamics of the globalization of knowledge production. As such, analyses that discard global trends in human mobility fail to capture important shifts in the global trends of innovation. In this context, our study finds that migration reforms adopted in the U.S. generate important spillovers on other countries that go in the opposite direction, highlighting the existence of an international competition to attract talent. In essence, when the U.S. eases inflows to attract talent, other countries are hurt in terms of their innovative capacity and vice versa. Finally, we find that positive migration reforms help explain the increased importance of emerging markets in global knowledge production.

Our findings carry important policy implications. In particular, the severe asymmetry in the effects associated with positive and negative reforms underlines how policies deterring human capital mobility are heavily detrimental to local knowledge production and might be hard to reverse through subsequent improvements. This is particularly true when considering that other countries could benefit from attracting talent turned away from places like the U.S. Overall, as human mobility still faces important restrictions compared to other flows, this comes at the cost of lower innovation—one of the most important drivers of economic growth and prosperity—in the years to come. Our findings are also arguably a wake-up call for policy makers in the United States and suggest that having a competitive strategy to attract global talent is an important driver in maintaining the U.S.'s leadership role in global innovation.

References

Acemoglu, Daron, David H Autor, and David Lyle. 2004. "Women, war, and wages: The effect of female labor supply on the wage structure at midcentury." *Journal of political Economy*, 112(3): 497–551.

Agrawal, Ajay, Devesh Kapur, and John McHale. 2008. "How do spatial and social proximity influence knowledge flows? Evidence from patent data." *Journal of Urban Economics*, 64(2): 258–269.

Agrawal, Ajay, Devesh Kapur, John McHale, and Alexander Oettl. 2011. "Brain drain or brain bank? The impact of skilled emigration on poor-country innovation." *Journal of Urban Economics*, 69(1): 43–55.

Akcigit, Ufuk, John Grigsby, and Tom Nicholas. 2017. "Immigration and the Rise of American Ingenuity." *American Economic Review*, 107(5): 327–331.

Bahar, Dany. 2020. "The hardships of long distance relationships: time zone proximity and the location of MNC's knowledge-intensive activities." *Journal of International Economics*, 125: 103311.

Bahar, Dany, Prithwiraj Choudhury, Ernest Miguelez, and Signorelli Sara. 2021. "Global Mobile Inventors." mimeo.

Balsmeier, Benjamin, Mohamad Assaf, Tyler Chesebro, Gabe Fierro, Kevin Johnson, Scott Johnson, Guan-Cheng Li, Sonja Lück, Doug O'Reagan, Bill Yeh, et al. 2018. "Machine learning and natural language processing on the patent corpus: Data, tools, and new measures." *Journal of Economics & Management Strategy*, 27(3): 535–553.

Beerli, Andreas, Jan Ruffner, Michael Siegenthaler, and Giovanni Peri. 2021. "The abolition of immigration restrictions and the performance of firms and workers: Evidence from Switzerland." *American Economic Review*, 111(3): 976–1012.

Bernstein, Shai, Rebecca Diamond, Timothy James McQuade, and Beatriz Pousada. 2018. "The Contribution of High-Skilled Immigrants to Innovation in the United States." *Stanford University Graduate School of Business Working Paper.*

Blackwell, Matthew. 2013. "A framework for dynamic causal inference in political science." *American Journal of Political Science*, 57(2): 504–520.

Borusyak, Kirill, and Xavier Jaravel. 2017. "Revisiting event study designs." *Available at SSRN 2826228.*

Bosetti, Valentina, Cristina Cattaneo, and Elena Verdolini. 2015. "Migration of skilled workers and innovation: A European Perspective." *Journal of International Economics*, 96(2): 311–322.

Branstetter, Lee G., Raymond Fisman, and C. Fritz Foley. 2006. "Do Stronger Intellectual Property Rights Increase International Technology Transfer? Empirical Evidence from U. S. Firm-Level Panel Data*." *The Quarterly Journal of Economics*, 121(1): 321–349.

Branstetter, Lee, Guangwei Li, and Francisco Veloso. 2014. "The rise of international coinvention." In *The changing frontier: Rethinking science and innovation policy.* 135–168. University of Chicago Press.

Breschi, Stefano, and Francesco Lissoni. 2009. "Mobility of skilled workers and co-invention networks: An anatomy of localized knowledge flows." *Journal of Economic Geography*, 9(4): 439–468.

Breschi, Stefano, Francesco Lissoni, and Ernest Miguelez. 2017. "Foreign-origin inventors in the USA: Testing for diaspora and brain gain effects." *Journal of Economic Geography*, 17(5): 1009–1038.

Burchardi, Konrad B., Thomas Chaney, Tarek A. Hassan, Lisa Tarquinio, and Stephen J. Terry. 2019. "Immigration, Innovation and Growth." *Working Paper.*

Callaway, Brantly, and Pedro HC Sant'Anna. 2021. "Difference-in-differences with multiple time periods." *Journal of Econometrics*, 225(2): 200–230.

Card, David, Stefano DellaVigna, Patricia Funk, and Nagore Iriberri. 2020. "Are Referees and Editors in Economics Gender Neutral?" *The Quarterly Journal of Economics*, 135(1): 269–327.

Caves, Richard E. 1971. "International corporations: The industrial economics of foreign investment." *Economica*, 38(149): 1–27.

Choudhury, Prithwiraj. 2016. "Return migration and geography of innovation in MNEs: a natural experiment of knowledge production by local workers reporting to return migrants." *Journal of Economic Geography*, 16(3): 585–610.

Choudhury, Prithwiraj, and Do Yoon Kim. 2018. "The Ethnic Migrant Inventor Effect: Codification And Recombination of Knowledge Across Borders."

Cohen, Wesley M, and Daniel A Levinthal. 1990. "Absorptive capacity: A new perspective on learning and innovation." *Administrative science quarterly*, 128–152.

De Chaisemartin, Clément, and Xavier D'Haultfoeuille. 2022. "Difference-in-differences estimators of intertemporal treatment effects." National Bureau of Economic Research.

Doran, Kirk, and Chungeun Yoon. 2019. "Immigration and Invention: Evidence from the Quota Acts." *mimeo.*

Duflo, Esther. 2001. "Schooling and labor market consequences of school construction in Indonesia: Evidence from an unusual policy experiment." *American economic review*, 91(4): 795–813.

Freeman, Richard B., and Wei Huang. 2015. "Collaborating with People Like Me: Ethnic Co-Authorship within the U.S." *Journal of Labor Economics*, 33(S1): S289–S318.

Ganguli, Ina. 2015. "Immigration and Ideas: What Did Russian Scientists "Bring" to the United States?" *Journal of Labor Economics*, 33(S1): S257–S288.

Giroud, Xavier. 2013. "Proximity and investment: Evidence from plant-level data." *The Quarterly Journal of Economics*, 128(2): 861–915.

Glennon, Britta. 2020. "How do restrictions on high-skilled immigration affect offshoring? Evidence from the H-1B program." National Bureau of Economic Research.

Goodman-Bacon, Andrew. 2021. "Difference-in-differences with variation in treatment timing." *Journal of Econometrics*, 225(2): 254–277.

Gumpert, Anna. 2018. "The organization of knowledge in multinational firms." *Journal of the European Economic Association*, 16(6): 1929–1976.

Gurevich, Tamara, and Peter Herman. 2018. "The Dynamic Gravity Dataset: 1948-2016." USITC Working Paper 2018-02-A.

Hall, Bronwyn H, Adam B Jaffe, and Manuel Trajtenberg. 2001. "The NBER patent citations data file: Lessons, insights and methodological tools." *NBER working paper #8498*.

Hunt, Jennifer, and Marjolaine Gauthier-Loiselle. 2010. "How Much Does Immigration Boost Innovation?" *American Economic Journal: Macroeconomics*, 2(2): 31–56.

Jaffe, Adam B. 2017. "Patent Citation Data in Social Science Research : Overview and Best Practices." 68(January): 1360–1374.

Kerr, Sari Pekkala, and William R Kerr. 2018. "Global collaborative patents." *The Economic Journal*, 128(612): F235–F272.

Kerr, Sari Pekkala, William Kerr, Caglar Ozden, and Christopher Parsons. 2016. "Global talent flows." *Journal of Economic Perspectives*, 30: 83–106.

Kerr, William R. 2008. "Ethnic scientific communities and international technology diffusion." *The Review of Economics and Statistics*, 90(3): 518–537.

Kerr, W.R., and W. Lincoln. 2010. "The supply side of innovation: H-1B visa reforms and US ethnic invention." *Journal of Labor Economics*, 28(3).

Kogut, Bruce, and Udo Zander. 1996. "What firms do? Coordination, identity, and learning." *Organization science*, 7(5): 502–518.

Kortum, Samuel, and Josh Lerner. 1999. "What is behind the recent surge in patenting?" *Research policy*, 28(1): 1–22.

Lissoni, Francesco. 2018. "International migration and innovation diffusion: an eclectic survey." *Regional Studies*, 52(5): 702–714.

Miguélez, Ernest. 2018. "Inventor diasporas and the internationalization of technology." *World Bank Economic Review*, 32(1): 41–63.

Miguelez, Ernest, and Claudia Noumedem Temgoua. 2019. "Inventor migration and knowledge flows: A two-way communication channel?" *Research Policy*, 103914.

Monath, Nicolas, Christina Jones, and Sarvo Madhavan. 2020. "PatentsView: Disambiguating Inventors, Assignees, and Locations." American Institutes for Research.

Moser, Petra, Alessandra Voena, and Fabian Waldinger. 2014. "German Jewish Émigrés and US Invention." *American Economic Review*, 104(10): 3222–3255.

Prato, Marta. 2021. "The Global Race for Talent: Brain Drain, Knowledge Transfer and Growth."

Squicciarini, Mariagrazia, Hélène Dernis, and Chiara Criscuolo. 2013. "Measuring patent quality: Indicators of technological and economic value."

Trajtenberg, Manuel. 1990. "A penny for your quotes: patent citations and the value of innovations." *The Rand Journal of Economics*, 172–187.

Online Appendix for

Talent Flows and the Geography of Knowledge Production: Causal Evidence from Multinational Firms

A Additional Tables and Figures

A.1 Tables

Table A1: Summary of patents by country

	N. of patents		N. of GCP		N. of domestic patents		Sh. of migrant inventors		N. Obs
Country	Mean	sd	Mean	sd	Mean	sd	Mean	sd	count
Brazil	2,17	(3,53)	1,24	(1,90)	0,93	(2,44)	0,13	(0,31)	1944
Canada	3,57	(15,44)	1,36	(4,90)	2,21	(11,97)	0,20	(0,33)	26085
Chile	1,26	(0,72)	0,87	(0,81)	0,39	(0,68)	0,14	(0,34)	304
China	7,20	(44,05)	2,38	(8,94)	4,82	(40,14)	0,34	(0,38)	12408
Germany	7,87	(34,51)	1,71	(6,32)	6,16	(30,27)	0,12	(0,25)	34932
Spain	2,39	(4,72)	1,27	(2,17)	1,12	(3,36)	0,15	(0,33)	4037
United Kingdom	3,98	(10,04)	1,54	(3,87)	2,44	(7,69)	0,19	(0,33)	28420
India	6,03	(23,30)	2,99	(12,63)	3,04	(12,33)	0,20	(0,34)	6831
Japan	33,60	(150,96)	1,02	(3,31)	32,58	(149,06)	0,08	(0,20)	27914
Korea	33,27	(258,02)	1,46	(10,47)	31,81	(249,00)	0,18	(0,31)	6705
Mexico	2,02	(3,90)	1,21	(1,81)	0,82	(2,82)	0,11	(0,30)	1516
Philippines	2,18	(2,34)	1,31	(1,58)	0,87	(1,68)	0,17	(0,34)	488
Portugal	1,43	(1,49)	0,95	(0,87)	0,48	(1,26)	0,16	(0,37)	535
Taiwan	11,71	(56,67)	1,56	(8,53)	10,15	(51,81)	0,14	(0,29)	10163
United States	14,17	(86,11)	1,53	(11,22)	12,64	(77,03)	0,09	(0,21)	135637

Summary statistics computed for the sample of subsidiaries belonging to an MNE over the period spanning from 1990 to 2016.

Table A2: List of new trade agreements signed over the period

Country	Year	New agreement	New institution
Brasil	1991	enter eia, cu	
Brasil	2010	enter fta	
Canada	1994	enter eia	
Chile	1997	enter fta, eia	
China	2001	enter psa, pta	enter WTO
China	2003	enter fta, eia	
India	2000	enter fta	
India	2005	enter eia	
Japan	2002	enter fta, eia, psa	
Korea	2004	enter fta, eia	
Mexico	1994	enter fta, eia	
Philippines	1993	enter fta	
Philippines	2004	enter eia	
Taiwan	2002		enter WTO
Taiwan	2004	fta, eia, pta	
United States	1994	enter eia	

Note: Legend: eia - economic integration agreement, cu - customs union, fta - free trade agreement, psa - partial scope agreement, pta - preferential trade agreement. No country in our sample exited an agreement over our period of interest.

Table A3: List of EU enlargements that took place over the period

Year	Event
1995	Austria, Swden, and Finland join the EU.
2004	Malta, Cyprus, Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Slovenia, Hungary join the EU.
2007	Romania and Bulgaria join the EU.
2013	Croatia joins the EU.

Events linked to the EU enlargement that affect Germany, Portugal, Spain and the United Kingdom in our sample.

Table A4: Effect on GMIs and patents by MNE size

	(1) N. GMIs (asinh)	(2) N. Patents (asinh)
VARIABLES	OLS	OLS
Exposure x pos. ref.	0.0637***	0.0785***
	(0.0134)	(0.0177)
Exposure x pos. ref. x small MNE	-0.0788***	-0.116***
	(0.0131)	(0.0173)
Exposure x neg. ref.	-0.00151	-0.0733**
	(0.0233)	(0.0301)
Exposure x neg. ref. x small MNE	-0.0997***	-0.118***
	(0.0246)	(0.0317)
Exposure	0.212***	0.550***
	(0.0176)	(0.0241)
Observations	166,360	166,360
R-squared	0.518	0.552

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Small MNEs identify the 50% of the sample with the smallest number of subsidiaries. Initial N. patents in the subsidiary interacted with year dummies, MNE x year fixed effects and country x year fixed effects included in all regressions. Period of analysis: 1990-2016. Continuous exposure to the reforms is computed as the mobility rate of inventors observed within all the other subsidiaries of the MNE over the preceding 5 years.

Table A5: Effect on patents by team composition

	(1)	(2)	(3)	(4)	(5)	(6)
	N. Patents (asinh)		N. GCPs (asinh)		N. Domestic patents (asinh)	
	Teams w. GMIs	T. wout. GMIs	Teams w. GMIs	T. wout. GMIs	Teams w. GMIs	T. wout. GMIs
VARIABLES	OLS	OLS	OLS	OLS	OLS	OLS
Exposure x positive ref.	0.0208***	0.0175*	0.00722**	0.00457	0.0226**	0.0153
	(0.00780)	(0.00946)	(0.00326)	(0.00280)	(0.00886)	(0.00997)
Exposure x negative ref.	-0.0657***	-0.161***	-0.0104*	-0.0188***	-0.0688***	-0.178***
	(0.0116)	(0.0155)	(0.00579)	(0.00461)	(0.0135)	(0.0167)
Exposure	0.272***	0.612***	0.0793***	0.0761***	0.322***	0.676***
	(0.0198)	(0.0268)	(0.00985)	(0.00808)	(0.0235)	(0.0292)
Observations	166,360	166,360	166,360	166,360	166,360	166,360
R-squared	0.593	0.534	0.697	0.650	0.457	0.517

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Columns (1), (3) and (5) use as outcome patents filed by teams that include at least 1 GMI, while columns (2), (4) and (6) use as outcomes patents filed by teams of never-movers. Initial N. patents in the subsidiary interacted with year dummies, MNE x year fixed effects and country x year fixed effects included in all regressions. Period of analysis: 1990-2016. Continuous exposure to the reforms is computed as the mobility rate of inventors observed within all the other subsidiaries of the MNE over the preceding 5 years.

Table A6: Effect on patent quality

	(1)	(2)	(3)	(4)	(5)
	Generality per pat (asinh)	Originality per pat (asinh)	Radicalness per pat (asinh)	N. of breakthrough per pat (asinh)	N. of citations per pat (asinh)
VARIABLES	OLS	OLS	OLS	OLS	OLS
Exposure x positive ref.	6.99e-05	-0.000344**	-8.49e-05	-8.26e-05	0.000649
	(0.000257)	(0.000174)	(0.000282)	(0.000116)	(0.00182)
Exposure x negative ref.	-0.000357	-0.000131	-0.00104	-9.22e-05	-0.0133***
	(0.000660)	(0.000440)	(0.000684)	(0.000443)	(0.00494)
Exposure	-0.000657	0.00102	0.00337***	-0.000211	0.0638***
	(0.000932)	(0.000652)	(0.000976)	(0.000444)	(0.00598)
Observations	129,929	144,936	144,952	146,221	146,221
R-squared	0.729	0.729	0.704	0.719	0.773

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Columns (1), (2), and (3) weight the count of the number of patents by the generality, originality, and radicalness coefficients, respectively, and then divide them by the patent count. Column (4) computes the share of patents that are considered breakthrough. Column (5) computes the number of citations per patent. Standard errors clustered at the subsidiary level. Initial N. patents in the subsidiary interacted with year dummies, MNE x year fixed effects and country x year fixed effects included in all regressions. Period of analysis: 1990-2016. Exposure to the reforms is computed as the mobility rate of inventors observed within all the other subsidiaries of the MNE over the preceding 5 years.

Table A7: Spillover effects of reforms across countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	N. of patents (asinh)								
	US spillovers	CA spillovers	CN spillovers	DE spillovers	GB spillovers	IN spillovers	JP spillovers	KR spillovers	TW spillovers
VARIABLES	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Exposure x other pos. ref.	-0.0414**		0.00616	-0.00586	0.0891*	-0.00154	-0.0124*	0.000127	-0.0404***
	(0.0161)		(0.0112)	(0.0111)	(0.0481)	(0.0209)	(0.00731)	(0.00400)	(0.0131)
Exposure x other neg. ref.	0.0435**	0.0189	-0.0462		-0.0506				-0.0519
	(0.0176)	(0.0278)	(0.0376)		(0.0361)				(0.0519)
Exposure x own pos. ref.	0.0148	0.0128	0.0143	0.0148	0.0136	0.0139	0.0165*	0.0138	0.0176*
	(0.00953)	(0.00903)	(0.00936)	(0.00932)	(0.00920)	(0.00906)	(0.00930)	(0.00931)	(0.00925)
Exposure x own neg. ref.	-0.150***	-0.145***	-0.141***	-0.136***	-0.147***	-0.140***	-0.131***	-0.141***	-0.131***
	(0.0166)	(0.0150)	(0.0156)	(0.0151)	(0.0154)	(0.0150)	(0.0145)	(0.0153)	(0.0139)
Exposure	0.603***	0.524***	0.558***	0.536***	0.561***	0.532***	0.554***	0.530***	0.577***
	(0.0390)	(0.0268)	(0.0351)	(0.0258)	(0.0348)	(0.0250)	(0.0271)	(0.0373)	(0.0516)
Observations	166,360	166,360	166,360	166,360	166,360	166,360	166,360	166,360	166,360
R-squared	0.544	0.544	0.544	0.544	0.544	0.544	0.544	0.544	0.544

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Each columns adds to the main specification an additional interaction between exposure and reforms taking place in another country, to test spill-overs. For instance, column (1) test the effect of reforms taking place in the US on patenting in other countries, controlling for the effect of own reforms. Initial N. patents in the subsidiary interacted with year dummies, MNE x year fixed effects and country x year fixed effects included in all regressions. Period of analysis: 1990-2016. Continuous exposure to the reforms is computed as the mobility rate of inventors observed within all the other subsidiaries of the MNE over the preceding 5 years.

Table A8: Effect on share of patents filed in emerging markets

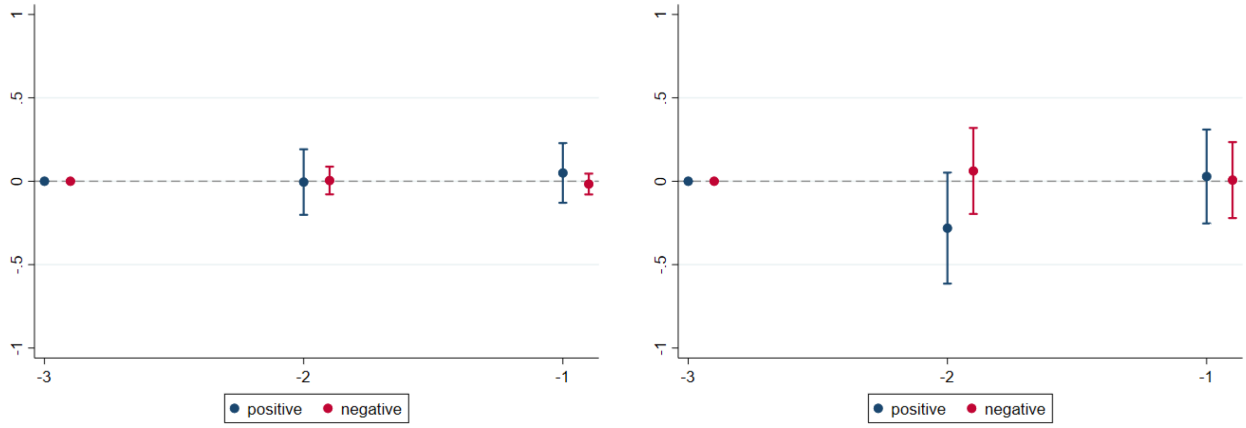
	(1)	(2)	(3)	(4)	(5)	(6)
	Share of global patents filed by subsid.		Share of global GCPs filed by subsid.		Share of global domestic pat. filed by subsid.	
VARIABLES	OLS	OLS	OLS	OLS	OLS	OLS
Exposure x pos. ref.	0.00188	-0.00294**	7.75e-05	-0.00192***	0.00226	-0.00260**
	(0.00142)	(0.00125)	(0.000343)	(0.000622)	(0.00159)	(0.00131)
Exposure x neg. ref.	-0.00931***	-0.00686***	-0.00133**	-0.000372	-0.0102***	-0.00773***
	(0.00207)	(0.00166)	(0.000605)	(0.000450)	(0.00225)	(0.00185)
Exposure x emerging M.		-0.0196***		-0.00919***		-0.0198***
		(0.00554)		(0.00250)		(0.00580)
Exposure x pos. ref. x emerging M.		0.00637***		0.00248***		0.00651**
		(0.00231)		(0.000773)		(0.00256)
Exposure x neg. ref. x emerging M.		0.00405		0.00159*		0.00457
		(0.00258)		(0.000922)		(0.00285)
Exposure	0.0182***	0.0290***	0.00545***	0.0103***	0.0192***	0.0300***
	(0.00403)	(0.00593)	(0.00122)	(0.00229)	(0.00436)	(0.00622)
Observations	166,360	166,360	166,360	166,360	166,360	166,360
R-squared	0.256	0.258	0.366	0.367	0.252	0.253

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
The outcomes measure the share of global patents, GCPs, and domestic patents produced in a year filed by each subsidiary. emerging markets are defined as the 50% of the sample with the lowest share of global patents observed over the period 1985-1990. Standard errors clustered at the subsidiary level. Initial N. patents in the subsidiary interacted with year dummies, MNE x year fixed effects and country x year fixed effects included in all regressions. Period of analysis: 1990-2016. Exposure to the reforms is computed as the mobility rate of inventors observed within all the other subsidiaries of the MNE over the preceding 5 years.

A.2 Figures

Figure A1: Additional pre-trend tests

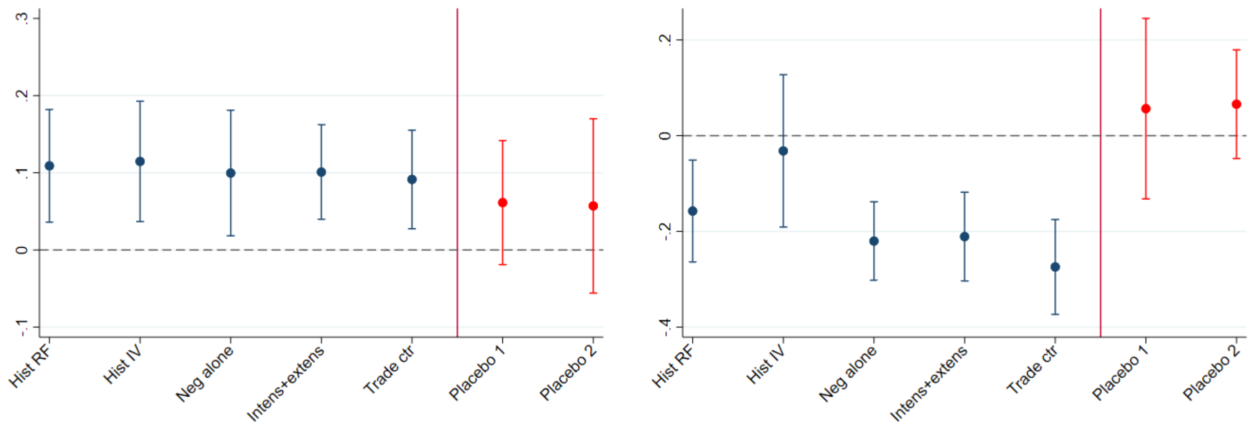
(a) N. GCPs (asinh) **(b)** N. domestic patents (asinh)



These graphs plot the dynamic effects obtained by interacting the exposure measure with dummies for the 3 years preceding the first reform in each country. Time t-3 is normalized to zero. The model is estimated separately for positive and negative reforms. The bars represent the 95% confidence intervals.

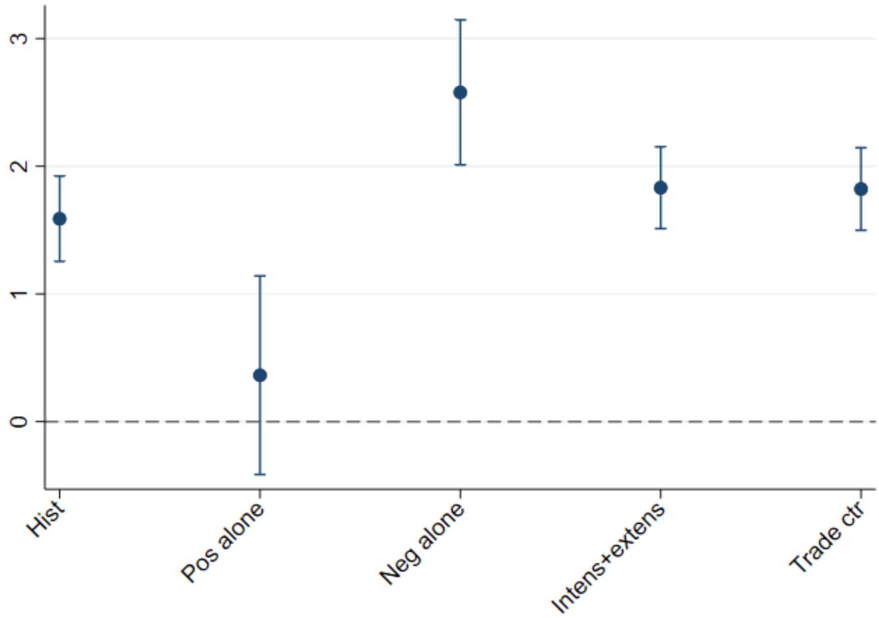
Figure A2: Robustness tests on N. of GMIs (asinh) - reduced form

(a) Effect of positive reforms **(b)** Effect of negative reforms



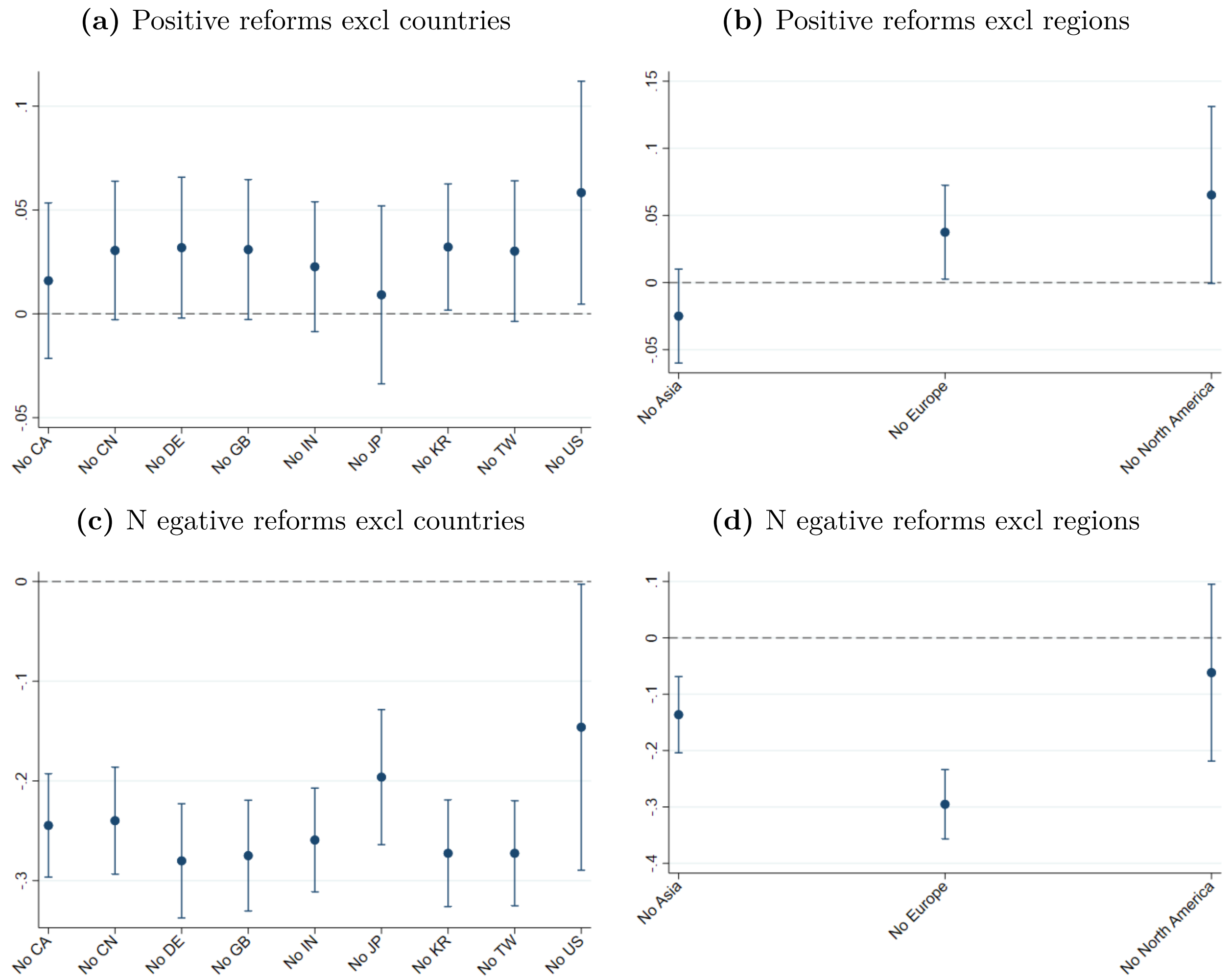
Each dot represents the result obtained from a separate regression, while the vertical line reports the 95% confidence interval. To ease interpretation the coefficients are rescaled by $\beta[Exposure]$, such that the vertical axes can be read as growth rates relative to exposure alone. The coefficients in blue concern regressions with slightly modified samples or methodology, while the ones in red are two distinct placebo tests.

Figure A3: Robustness tests on N. of Patents (asinh) - 2SLS coefficients



Each dot represents the result obtained from a separate regression, while the vertical line reports the 95% confidence interval.

Figure A4: Effect of excluding one country / region on N. of Patents (asinh) - reduced form



(a) Positive reforms excl countries

(b) Positive reforms excl regions

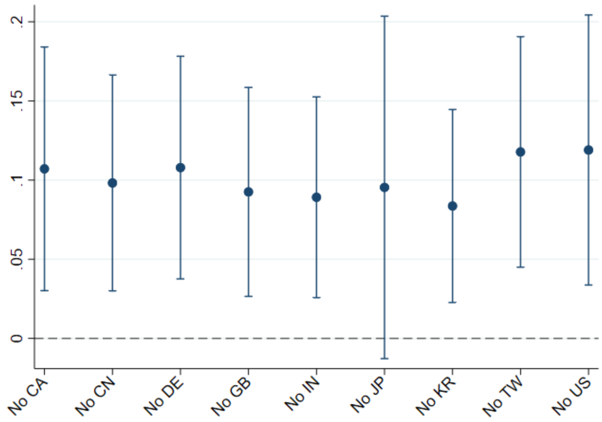
(c) N egative reforms excl countries

(d) N egative reforms excl regions

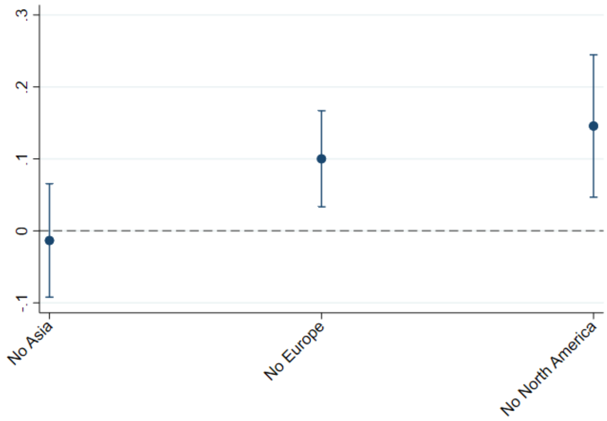
Each dot represents the result obtained from a separate regression, while the vertical line reports the 95% confidence interval. To ease interpretation the coefficients are rescaled by $\beta[Exposure]$, such that the vertical axes can be read as growth rates relative to exposure alone. The coefficients are obtained after excluding 1 by 1 the countries or regions in our sample that account for at least 5,000 observations.

Figure A5: Effect of excluding one country / region on N. of GMIs (asinh) - reduced form

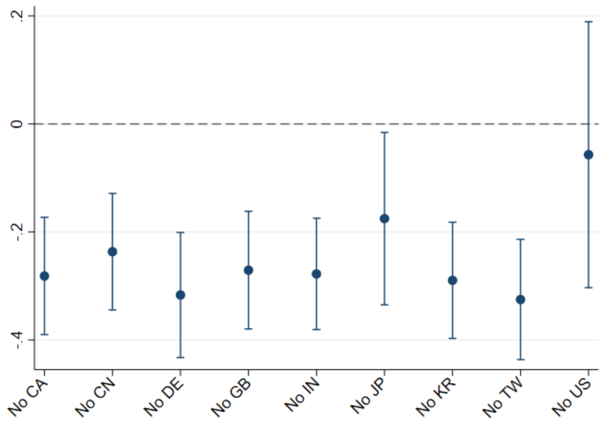
(a) Positive reforms excl countries



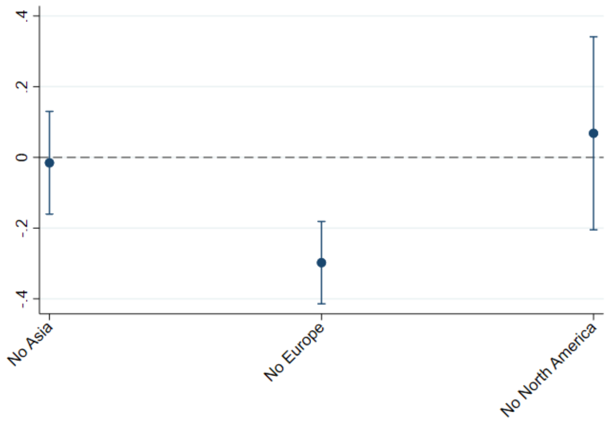
(b) Positive reforms excl regions



(c) Negative reforms excl countries



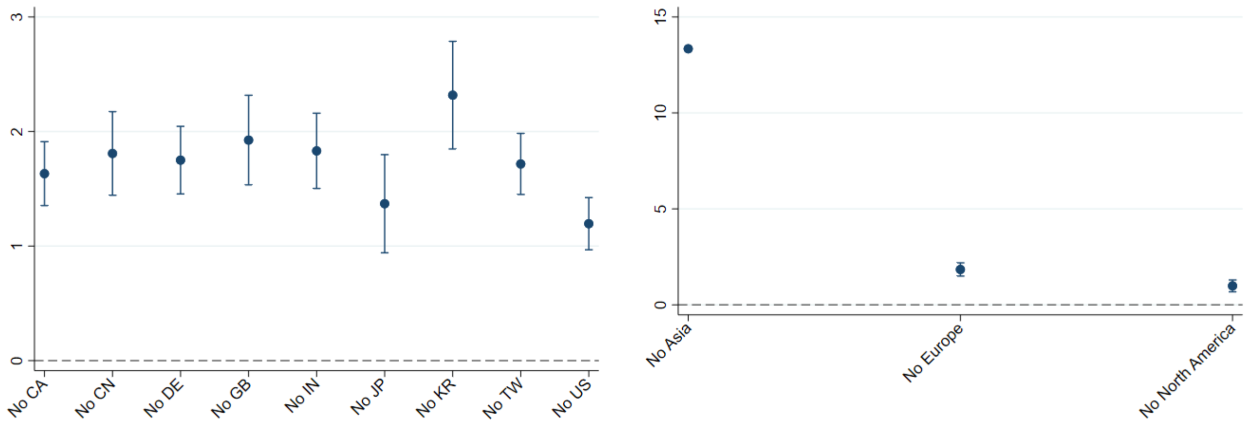
(d) Negative reforms excl regions



Each dot represents the result obtained from a separate regression, while the vertical line reports the 95% confidence interval. To ease interpretation the coefficients are rescaled by $\beta[Exposure]$, such that the vertical axes can be read as growth rates relative to exposure alone. The coefficients are obtained after excluding 1 by 1 the countries or regions in our sample that account for at least 5,000 observations.

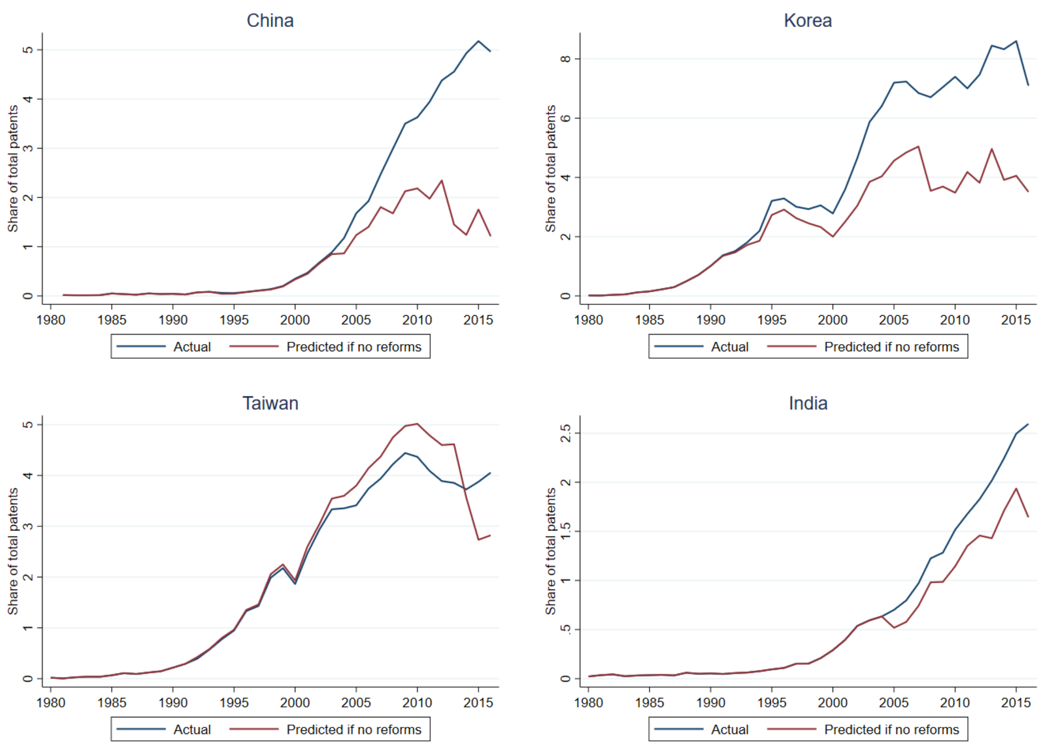
Figure A6: Effect of excluding one country / region on N. of Patents (asinh) - 2SLS coefficients

(a) Regressions excl countries **(b)** Regressions excl regions



Each dot represents the result obtained from a separate regression, while the vertical line reports the 95% confidence interval. Confidence intervals not reported in regression excluding Asia for presentation purposes. They are extremely large, which is explained by the instrument being weak in this sample (K-P F-statistic below 1).

Figure A7: Predicted trends in share of global patents after subtracting the effect of reforms



The actual outcomes are the total patent shares observed in each country across the period of interest. We obtain the predicted outcomes by subtracting the predicted effect of positive and negative migration reforms from the actual outcomes. We select the countries in the low initial share group that have a large number of observations.

B Validity of the Main Assumptions

The main assumption of difference-in-differences estimations is the common trend hypothesis. The test for pre-trends is reported in the main analysis. The second central assumption that is made by our strategy, driven by the choice of introducing reform events as count variables, is that the average treatment effect of a given reform type is equivalent across events, which means that the magnitude of the effect of the first reform in a given country is comparable to the second reform, the second is comparable to the third, and so forth. To test this assumption, we estimate the following model:

$$Y_{fct} = \beta_0 + \beta_1 exp_{fct} + \sum_{r=1}^{2,3} \alpha_r Ref_{ct}^r \times exp_{fct} + \gamma_{ct} + \delta_{ft} + \epsilon_{fct}, \tag{B1}$$

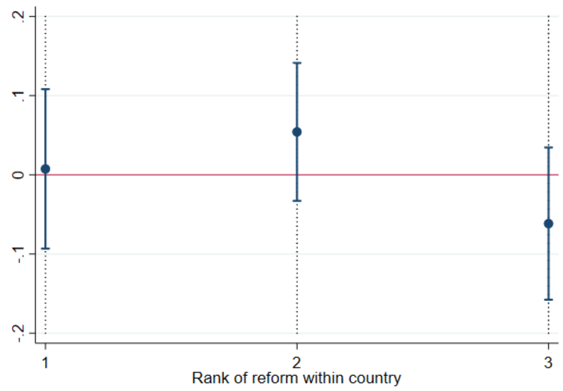
where r indexes up to three consecutive positive reforms and up to two negative reforms in a given country, Ref_{ct}^r identifies the period in country c after reform r and prior to reform $r+1$ and α_r recovers the distinct effect of each subsequent reform from the first to the third.[38] We run the regression separately for positive and negative reforms on the sample of countries that experience at least one of them and on the sample of years preceding the third reform of the same type within each country.

The recovered coefficients are reported in figure B8, for the number of patents and the number of GMIs observed in the subsidiary. What we can observe is that the effect is slightly increasing in magnitude, with the second positive reform having a larger effect than the first and the second negative reform having a slightly larger effect than the first. Nonetheless, the 95% confidence intervals overlap, suggesting that the effects are comparable in terms of magnitude.

[38] We limit ourselves to two consecutive negative reforms and three consecutive positive reforms because the sample of countries experiencing more than that becomes very small.

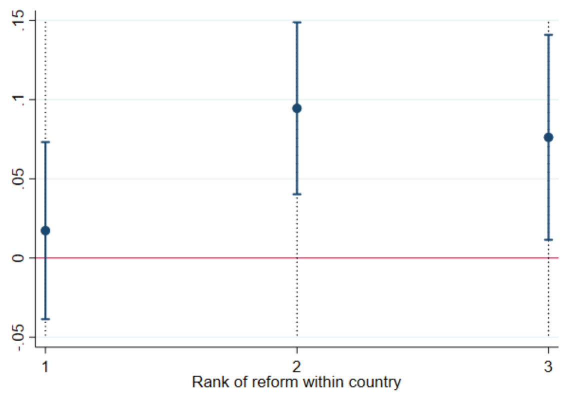
Figure B8: Test for equivalence of effect across subsequent reforms

(a) asinh Patents, subsequent positive reforms



(b) asinh Patents, subsequent negative reforms

(c) asinh GMIs, subsequent positive reforms



(d) asinh GMIs, subsequent negative reforms

These graphs plot the separate effect of the first and second reform taking place in a country obtained by running equation B1 on the sample cut before the third subsequent reform. The model is estimated separately for positive and negative reforms. The bars represent the 95% confidence intervals.

B.1 Dynamic Effects

The standard model used to recover the dynamic treatment effects is the following:

$$Y_{fct} = \beta_0 + \beta_1 exp_{fct} + \sum_{k=-3}^{+3} \mathbb{1}_{\{t_{PRef_c}+k=t\}} \alpha_k exp_{fct} + \sum_{k=-3}^{+3} \mathbb{1}_{\{t_{NRef_c}+k=t\}} \theta_k exp_{fct} + \gamma_{ct} + \delta_{ft} + \epsilon_{fct}, \quad \text{(B2)}$$

where k indexes time to the nearest reform, $\mathbb{1}(t_{PRef_c} + k = t)$ is a series of indicator variables indexing observations k periods before or after a positive reform event, and $\mathbb{1}(t_{NRef_c} + k = t)$ is the equivalent for negative reforms. exp_{fct} represents our exposure measure. Here, α_k and θ_k identify the dynamic marginal treatment effects of positive and negative reforms at event-time k relative to an omitted baseline period (the year prior to reform enactment). This estimate can be thought of as a by-year estimate of the β_2 coefficients in equation 1 that comes at the expense of omitting information on reform events' links to all but the most proximate years.

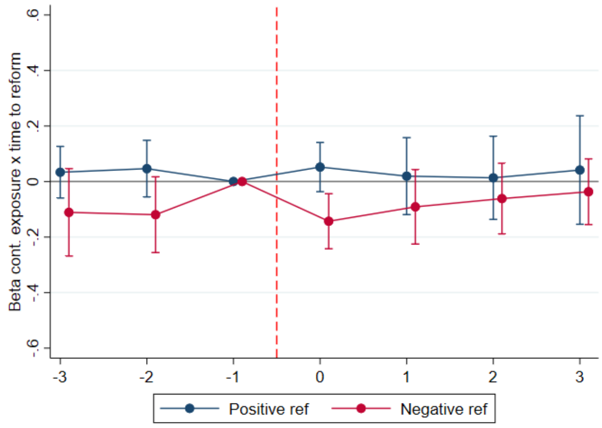
In the ideal setting, we would estimate the model reported in equation B2 on the full sample, assigning the timing with respect to the closer reform. Nevertheless, in our case the high frequency of reforms observed in certain countries makes it really difficult to distinguish between pre- and post-periods. Thus, we adopt an alternative strategy: We perform a Monte Carlo simulation in which we randomly draw 1,000 times one single positive and one single negative reform for each country, which we use to estimate equation B2. We then take the average over the 1,000 different α_k and θ_k that we obtain, and we compute bootstrapped standard errors.[39]

Figure B9 plots the point estimates and corresponding 90% confidence intervals of α_k and θ_k for the three years leading to a reform and the three years following it. The year preceding the reform is used as a reference point. Figures B9a and B9b show that the number of GMIs and patent production in subsidiaries with different levels of exposure followed the same exact trends in the years preceding a positive reform and, if anything, they showed slightly higher growth in the years preceding a negative reform. After the implementation of a positive policy, there is an increase in the number of patents filed by the subsidiary, but the effect on individual post-period years is not significant. After a negative reform, most exposed subsidiaries see a decline in patents compared to the rest. When we disentangle between GCPs and domestic patents (figure B9c and figure B9d), we find no effect of positive reforms on GCPs and generally a larger effect in magnitude on domestic patents. These results are broadly consistent with the main

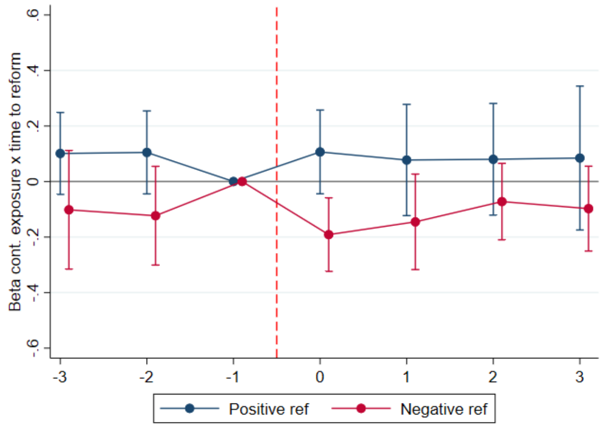
[39]In countries where both positive and negative reforms take place, each time we draw one from each of the two types. For the others, we draw only from the reform type that they have. In order to maintain all the observations in the regressions, for countries without positive reforms, we set all the time-to-reform dummies to 0, and we do the same for countries without negative reforms.

Figure B9: Dynamic effect of reforms

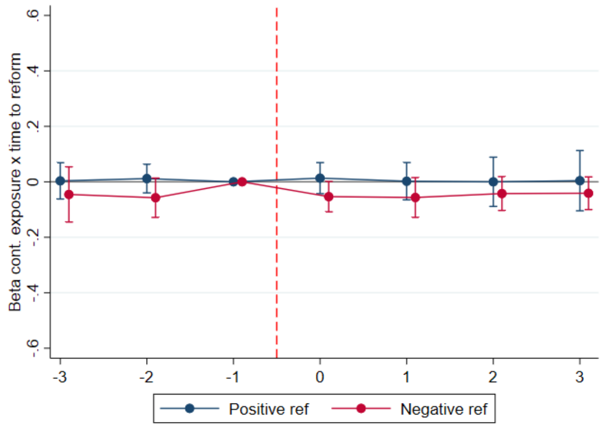
(a) asinh GMIs



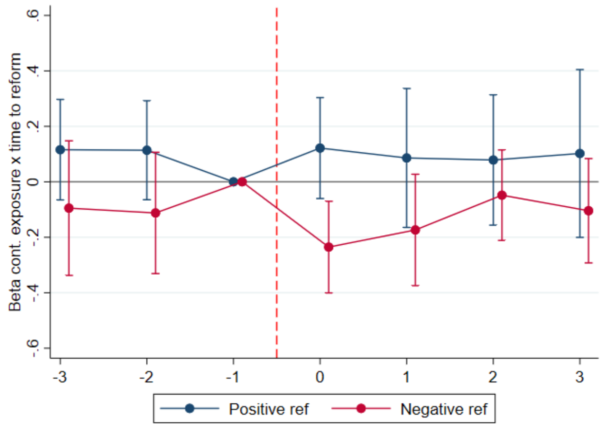
(b) asinh Patents



(c) asinh GCPs



(d) asinh Domestic Patents



These graphs plot the dynamic effects obtained by running equation B2 on the three years preceding and the three years following the reforms, for total number of patents (panel a), GCPs (panel b), and domestic patents (panel c). The bars represent the 90% confidence intervals. Instead of estimating the model on the full sample of reforms, the graph is obtained by running a Monte Carlo simulation on 1,000 random samples where one positive and one negative reform are picked for each country and by averaging the effect over all of them.

(static) analysis, but with the difference that the majority of the coefficients on individual post-period years are insignificant. This might be explained by the fact that positive reforms have a significant effect if all post-reform years are considered together (including long-term effects), but not if individual years are considered separately. This exercise also underlines the difficulty performing the standard event study analysis in a context including multiple reforms clustered in time.

C Reform Data Construction

This appendix focuses on the collection and construction of the database of unilateral reforms to migration policy impacting high-skilled migrants. The first subsection provides the list of reforms, and the second subsection describes the collection of the larger dataset of reforms. The full dataset is available upon request. To select our sample, we started from the 16 countries used by Branstetter, Fisman and Foley (2006), who study the impact of systematic reforms designed to strengthen and standardize intellectual property on MNEs' foreign direct investments from 1982 to 1999. We depart from their list by adding four major innovation countries that account for more than 1% of GMIs (Canada, Germany, the United Kingdom, and the United States) and by dropping their five countries that patent very little and account for less than 0.2% of GMIs (Argentina, Colombia, Thailand, Turkey, and Venezuela). Table C9 reports the sample selection criteria, where BFF indicates the sample of Branstetter, Fisman and Foley (2006) and BCSS indicates our sample.

C.1 Study Reforms

For each reform examined in this study, table C10 lists the country impacted, the year of implementation, the estimated impacts on migrants, and a brief description of the reform.

Table C10: Description of study reforms

Country	Year	Title	Impacts	Brief Description
Brazil	2014	Amendment of Foreign Statute	Increase Volume, Increase Rights	The amended act supports electronic visa, and gives Ministry of Foreign Affairs the power to simplify visa application process. It also implies that aliens who wish to travel to Brazil on business, as an artist or athlete does not need a visa if their country treat Brazilians the same.

Continue on next page

Table C10 – continued from previous page

Country	Year	Title	Impacts	Brief Description
Canada	2002	Immigration and Refugee Protection Act	Decrease Rights	The act was the primary federal legislation regulating immigration to Canada and created a high-level framework detailing the goals and guidelines the Canadian government with regard to immigration to Canada by foreign residents. It sets out the core principles and concepts that govern Canada's immigration and refugee protection programs, including provisions relating to refugees, sponsorships and removals, detention reviews and admissibility hearings, and the jurisdiction and powers of tribunals.
Chile	2005	Ratification of 'The United Nations Convention on the protection of the rights of all migratory workers and their families'	Increase Rights	Chile ratified the United Nations convention on migrant workers and developed policies to assist in their integration. Allowed immigrant children to attend school and be treated equally to native students regardless of migratory status. Healthcare access in public hospitals were granted to immigrant children and pregnant women.
China	1994	The Hundred Talents Program	Increase Volume	The initiative is one of the earliest and biggest programs in China to attract qualified scholars to conduct research in China. One-time research grant of up to $2M RMB plus housing allowance are provided to qualified personnel. Applicants need to be under 40 and work full time in China.

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Table C10 – continued from previous page

Country	Year	Title	Impacts	Brief Description
China	1996	Administration of Employment of Foreigners in China	Decrease Rights	The law set the guidelines for the employment of foreigners in China. This includes provisions such as - Employees without Chinese nationality must obtain an employment license; foreigners entering China for employment purposes must hold an employment visa and can only be hired for positions which cannot be filled by a Chinese national; provides exemptions for UN employees. Labour contracts with foreign workers shall not exceed 5 years. Wage, minimum wage, labour disputes and working conditions of foreign employees shall be governed by local Chinese law, etc.
China	2004	Decree No. 47, 2004: Measures for the Administration of Examination and Approval of Aliens' Permanent Residence in China	Increase volume	The act specified ""Green Card"" policy for China into 3 categories: technical, investment, and marriage. To qualify for technical immigration, aliens need to hold title of associate director/associate professor equivalent or above. Investment category required at least $500,000 investment into national recommended industries or some less developed regions. Marriage category required living in China for at least 5 years with spouse who is Chinese or has obtained permanent residency.
China	2013	Administrative Regulations of the People's Republic of China on Entry and Exit of Foreigners	Increase volume	Visa categories were increased from 8 to 12 with adjusted scopes for F, X and Z visa. ""Illegal employment"" fine increased from 1,000 RMB to 10,000 RMB per person for the employer but not exceeding 100,000 RMB. Foreign individual would be fined for 5,000 - 20,000 RMB with potential detention of up to 15 days. Foreign students with X visa were allowed to work off-campus.
China	2008	The Thousands Talent program	Increase Volume	The program established in 2008 by the central government of China to recognize and recruit leading international experts in scientific research, innovation, and entrepreneurship.

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Table C10 – continued from previous page

Country	Year	Title	Impacts	Brief Description
Germany	2000	The Green Card Initiative	Increase volume	This initiative provided a non-bureaucratic means of bringing foreign experts in the information and communication technology (ICT) field to Germany. 20,000 temporary visas were created, but the program was discontinued at the end of 2004.
Germany	2005	Immigration Act of 2005 (Complete Overhaul of German Migration Policy)	Increase volume; Increase rights	This act amended the Nationality Act and introduced a new Residence Act. It simplified and reduced the number of residence titles to two: a temporary residence permit and a permanent settlement permit. For the first time, the focus was placed on long-term permanent residency for migrants, in particular for skilled workers, and on integration measures.
Germany	2012	EU Blue Card (Article 19a, German Residence Act)	Increase volume	The Blue Card introduced based on the Blue Card Directive (Directive 2009/50/EC) was designed to create a European equivalent of the popular US Green Card. In particular, this law has streamlined visa application and right of residence procedures for skilled professionals from abroad. Highly qualified members of third countries can apply for the Blue Card. Relatives of the applicant receive a work permit in parallel.
Germany	2016	Integration Act of 2016	Increase rights	The Integration Act and the Regulation on the Integration Act aim to facilitate the integration of refugees into German society.
India	2005	Ramanujan Fellowship	Increase Volume	Ramanujan Fellowship is meant for brilliant Indian scientists and engineers from outside India to take up scientific research positions in India, those Indian scientists/engineers who want to return to India from abroad. The fellowship is scientist-specific and very selective. The Ramanujan Fellows could work in any of the scientific institutions and universities in the country and they would be eligible for receiving regular research grants through the extramural funding schemes of various S&T agencies of the Government of India.

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Country	Year	Title	Impacts	Brief Description
India	2016	India Corporate Internship	Increase Volume	The program aims at attracting overseas Indians who are currently pursing graduate studies outside India in Management/Engineering/-Science & Technology to intern in India for 2 to 6 months. In summer 2016, 60 paid internship opportunities will be available at 23 well-known Indian companies.
Japan	1992	Foreign Trainee Program	Extend Duration	For foreign trainees in Japan, if certain proficiency was achieved for language and professional skills, they were allowed for another 1 year and 3 month of work status.
Japan	1993	Technical Internship Trainee Program	Increase Volume	Foreign workers were issued training status for 1 year and 2-year work status if they pass tests at the end of the training. Trainees could only be sent from Japanese company's overseas branch.
Japan	2010	Basic Guidelines related to Policies for Foreign Residents of Japanese Descent	Increase Rights	This guideline promotes the acceptance of Japanese descendants who lacks language proficiency. The government will provide daily life support, offer jobs and respect diverse culture.
Japan	2012	Point System for Highly Skilled Foreign Professionals	Increase Volume	A point-based system was established to attract highly-skilled foreign professionals. Three types of professionals are given preferential immigration treatment: advanced academic researcher, advanced specialist/technician and advanced business managers. In each category, points were given to academic achievement, work experience, annual income and other factors. If total points reach 70, the professional will be granted a status of residence.

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Table C10 – continued from previous page

Country	Year	Title	Impacts	Brief Description
Japan	2014	The Act for Partial Amendment of the Immigration Control and Refugee Recognition Act	Increase Volume	Reorganizes the statuses of residence such as by establishing a status of residence for foreign nationals who possess advanced and specialized skills in order to promote the acceptance of foreign nationals who will contribute to the development of the Japanese economy amid economic globalization, and takes such measures as further facilitating the procedures for landing examinations, etc.
Japan	2015	Revised Point System for Highly Skilled Foreign Professionals	Increase Volume	Highly skilled professional became a type of visa. The revision is meant to make foreign professionals come to Japan more easily than before.
Mexico	2010	Reform to Article 67 of General Law of Population	Increase Rights	The revision allowed migrants to report human rights violation and granted migrants rights to receive aid in event of disasters and medical treatment if their life is in danger.
Mexico	2011	Migratory Act of May 25th	Increase Rights	The Migration Law eliminated over 70 articles in the Gernal Law of Population and is now the immigration law in Mexico. The law guaranteed foreigners the right to education, health services and judicial rights. The Center for Evaluation and Control of Trust would be created to oversee the conduct of the immigration authorities. The new law has four new categories of immigration permits: Visitor, Student, Temporary Resident, and Permanent Resident. Recognition of the right's immigrants acquire, whereas foreigners with family, labor, and business ties to Mexico generate a series of rights and commitments as of the time in which they begin their day-to-day lives in Mexico, even if they have fallen into irregular migratory status for administrative reasons and provided, they have complied with applicable law.

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Country	Year	Title	Impacts	Brief Description
Mexico	2012	Guidelines for Immigration Procedures and Proceedings	Decrease Rights	Mexican companies wishing to hire foreigners must obtain evidences of registration with the National Immigration Institute. Foreigners cannot change status within Mexico from a visitor visa to a work permit.
Mexico	2014	Amendment to the Immigration Law	Extend Duration, Increase Volume	A new 10-year visitor's visa was introduced for family members of a Mexican citizen or of current temporary resident and permanent resident. Income and saving requirements for temporary resident and permanent resident have been reduced.
Philippines	1996	Migrant Workers and Overseas Filipinos Act	Increase Volume	The act established the replacement and monitoring centre jointly responsible by the department of labor and employment, overseas workers welfare administration and Philippines overseas employment administration. The centre offers returnees skill training, job opportunities, livelihood programs and etc.
Philippines	2002	Balikbayan Program (Republic Act No. 9174)	Increase Volume, Increase Rights	This program amended the Republic Act No. 6768 enacted in 1989 and granted more benefits and privileges to the balikbayan (overseas Filipino returning to the Philippines, including former Filipinos who have acquired foreign citizenship). The program granted balikbayan and their immediate families visa-free entry and stay for up to one year and tax exemption for certain purchase.
Philippines	2009	Changes to Alien Employment Permits (Department Order 97-09)	Decrease Volume	The order aims to prevent foreigners from taking jobs that could be filled up by Filipinos. DOLE may inspect the establishments employing aliens to verify the legitimacy of the employment. Aliens whose Alien Employment Permit (AEP) application was denied would not be allowed to apply for a new AEP application.

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Country	Year	Title	Impacts	Brief Description
Philippines	2012	Changes to Alien Employment Permits (Department Order 120-12)	Decrease Volume	This change requires that aliens to appy for a new AEP if a new job position is assumed within their current organization or start employment in a new company. Fines were established for aliens found working in the Philippines without a valid AEP as well as for organizations employing them. Processing time of AEP application was reduced.
Philippines	2013	Extension of Visa Stay	Extend Duration	Duration of stay for aliens without visa from 151 countries (including US) was extended from 21 days for 30 days
Philippines	2015	Changes to Alien Employment Permits	Decrease Volume	This change affects aliens who wish to work in Philippines and the processes to acquire an AEP. Notable changes include a more detailed description of an AEP needs to be published in newspaper and on the DOLE for 30 days; an understudy training program for training two Filipino nationals is required for each AEP application; and the processing fees was increased.
Portugal	2001	Law-Decree nº4/2001 of January 10: immigration law	Increase Volume	A new temporary work visa category ""stay permit"" was created for foreigners who has a work contract. The stay permit was valid for one year with the possibility of extending to a maximum of five years. Foreigners were allowed to bring their family members to Portugal and at the end of the five-year period, foreigners can apply for a resident permit.
Portugal	2003	Law-Decree nº34/2003 of February 25: immigration law	Decrease Volume	""Stay permit"" was abolished in this version of the immigration law. A system of quotas was established based on a report on domestic skill shortage in each sector. Employers need to go through a complex procedure to employ foreigners.

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Country	Year	Title	Impacts	Brief Description
Portugal	2012	Golden Visa Program	Increase Volume	This scheme grants foreign individuals a golden visa (permanent residency) if they fall into three categories: 1) invest 500,000 in real estate; 2) make capital transfer of at least 1M Euro or 3) create 10 jobs. If visa holder stayed at least 7 days in year 1 and 14 days in the remaining 4 years, he/she can apply for citizenship.
South Korea	1991	Industrial and Technical Training Program for Foreigners (ITTP)	Increase Volume	This program allowed Korean companies overseas to train foreign employees. The trainees could stay for six months with a possible extension for another six months.
South Korea	1992	ITTP	Increase Volume	The change allowed small and medium businesses without overseas presence to bring in foreign trainees as well. The duration of stay for trainees was one year.
South Korea	1993	Industrial Trainee System (ITS)	Increase Volume	This program was an extended application of ITTP. The duration of stay for trainees was extended to two years. ITS specifically targeted small and medium enterprises in the manufacturing sector that was experiencing labor shortage. The quota for industrial trainee was set at 20,000.
South Korea	1994	ITS	Increase Volume	The quota for industrial trainee was increased to 30,000
South Korea	1995	A Measure Pertaining to the Protection and Control of Foreign Industrial and Technical Trainees	Increase Rights	Foreign trainees should be paid directly from the employers and at least the minimum wage set by the government. Trainees no longer need to surrender their passports to employers or to any other party.
South Korea	1996	ITS	Increase Volume	The quota for industrial trainee was increased to 80,000

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Country	Year	Title	Impacts	Brief Description
South Korea	1998	Working After Training Program for Foreigners	Extend Duration, Increase Rights	Foreign trainees who passed certain skill tests after a two-year training period were allowed to work in Korea for another year under visa category of ""working after training (E-8)"". Workers after training were entitled to the same rights enjoyed by their Korean colleagues.
South Korea	1999	Act on Immigration and Legal Status of Overseas Koreans (The Overseas Korean Act)	Increase Volume, Increase Rights	The act allowed overseas Korean to stay and work in Korea without restrictions upon receiving an Overseas Korean (F-4) visa. The act grants the same economic and social rights held by Korean citizens to overseas Korean.
South Korea	2002	ITS	Increase Volume	The quota for industrial trainee was increased to 85,500
South Korea	2004	Employment Permit System	Increase Volume	This program allows employers to hire foreign workers in the labor shortage industries such as agriculture & stockbreeding, fishery, construction and manufacturing with less than 300 regular workers. Foreign workers are granted 'Nonprofessional Employment' (E-9) visas.
South Korea	2007	Working Visit Program	Increase Volume, Extend Duration	This program grants ethnic Koreans who hold foreign citizenship, mainly from China and Soviet Unions a working visit (H-2) visa. Visa holders can freely enter and exit Korea for five years and get employed in any company in Korea for three years.
South Korea	2009	Contact Korea	Increase Volume; Increase Rights	Contact Korea is the government organization representing the Republic of Korea that is exclusively charged with the attraction of global talented professionals. Contact Korea includes an online platform for global talents to apply for jobs in both private and public sectors in Korea. The platform serves as a one-stop shop by providing services such as arranging online interviews, verfiying academic and professional background and dealing with visa and immigration issues.

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Country	Year	Title	Impacts	Brief Description
South Korea	2010	HuNet Korea Immigration Network and Policy	Increase Volume, Increase Rights	A new online visa application system (HuNet Korea) would be implemented to include visa application and job bank for foreign professionals. Re-entry procedure for foreign spouses and students was simplified. A point system would be implemented for professionals who wish to obtain resident or permanent resident status in Korea. Foreigners could also obtain residency by investing in real estate in designated local areas, for example in Jeju-si. Number of sites for naturalization interview tests were increased to make it more convenient for immigrants.
Spain	1996	Royal Decree 155/1996 - approving the implementation of regulations of Organic Law 7/1985	Increase Rights	This amendment stated that foreigners with legal status have the rights to access education and other resources. Foreigners could obtain permanent residency after 6 years or 5 years if they have permanent job permit.
Spain	2003	Organic Law 14/2003 - amendment to Organic Law 8/2000	Increase Rights, Increase Volume	This amendment increased rights to the family of legal foreigners, such as spouse could obtain his/her own residence permit when given work permit and children could obtain their own permit upon reaching adulthood. Each year government would review annual foreign worker quota.
Spain	2009	Organic Law 2/2009 - amendment to the Organic Law 4/2000	Increase Rights	This amendment added article 2b which focused on integration of immigrants. Article 6 stated that foreign residents have rights to vote in municipal elections. Article 12 stated that foreigners have access to healthcare under the same condition as citizens. Article 38s stated that highly qualified residence would be able to obtain residence permit and EU blue card.

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Country	Year	Title	Impacts	Brief Description
Taiwan	1992	Employment Service Act	Decrease Volume, Decrease Rights	The act was the first law in Taiwan to legalize hiring of certain foreign workers, strengthen the legal rights of employees, and impose sanctions on employers who hired illegal foreign laborers. Employment for foreign workers was limited to a maximum of two-year term and blue-collar foreign workers are prohibited to marry Taiwanese during employment.
Taiwan	2014	Amendments to the Regulations Governing Visiting, Residency, and Permanent Residency of Aliens	Extend Duration, Increase Rights	Adult children of foreign residents who grew up in Taiwan are able to apply for two three-year extensions of residency if they meet certain requirements. Foreign professionals who have completed their previous work assignments have up to six months of extended residency to seek new employment in Taiwan. Foreign students who graduated from Taiwan universities also have a six-month extension of residency. They qualify for employment without needing the two years of work experience as previously required.
Taiwan	2015	Global Recruiting Platform	Increase Volume	A Recruitment Policy Committee was established under the Executive Yuan that included representatives from ministries such as Economic Affairs, Education, Labour, Health and Welfare and National Immigration Agency. The platform aims to attract highly-skilled professionals from overseas to live and work in Taiwan.
UK	1996	Asylum and Immigration Act	Decrease rights	The act made it a criminal offence to employ anyone unless they had permission to live and work in the UK.
UK	2006	Immigration, Asylum and Nationality Act	Decrease Rights; Increase Rights	A five-tier points system for awarding entry visas was created. Those refused work or study visas had their rights of appeal limited. The act brought in on-the-spot fines of £2,000, payable by employers for each illegal employee, which could include parents taking on nannies without visas.

Continue on next page

Table C10 – continued from previous page

Country	Year	Title	Impacts	Brief Description
United States	1990	Immigration Act	Increase volume	Increased legal immigration ceilings. Created a diversity admissions category. Tripled the number of visas for priority workers and professionals with U.S. job offers.
United States	1998	American Competitiveness and Workforce Improvement Act (ACWIA)	Increase volume	increased this annual cap of H1B visas from 65000 to 115,000 for Fiscal Year 1999 and 2000; and 107,500 in Fiscal Year 2001. The cap returned to 65,000 starting with Fiscal Year 2002.
United States	2000	American Competitiveness in the 21st Century Act of 2000	Increase volume	The quota was increased to 195,000 H-1B visas in fiscal years 2001, 2002, and 2003 only. Non-profit research institutions sponsoring workers for H-1B visas became exempt from the H-1B visa quotas.
United States	2004	H-1B Visa Reform Act of 2004	Decrease volume	Reduction in the H-1B cap from 195,000 to 65,000 visas, but declaring exemptions for the first 20,000 applicants each year with graduate degrees. Additional restrictions and regulations for L-1 Visas (intra-company short visits).
United States	2009	Employ American Workers Act	Decrease volume	For employers who applied to sponsor a new H-1B and who had received funds under either the Troubled Asset Relief Program (TARP) or the Federal Reserve Act Section 13, the employers were required to attest that the additional H-1B worker would not displace any U.S. workers.
United States	2015	Rule about work authorization for certain H-4 holders	Increase rights	Allows certain spouses of H-1B workers to be eligible for work authorization.

Table C9: Criteria for the selection of the final sample

Country code	OECD	Share migrants (always)	N. Patents	N. GCPs	N. subsidiaries	BFF	BCSS	Reason of difference with BFF
US	1	5,2%	129214	14668	23158	0	1	More than 2000 subsid, more than 1% GMIs
JP	1	2,4%	44937	1420	2628	1	1	
KR	1	3,4%	17855	738	1337	1	1	
DE	1	1,5%	15772	3613	3222	0	1	More than 2000 subsid, more than 1% GMIs
GB	1	1,0%	7183	2650	2226	0	1	More than 2000 subsid, more than 1% GMIs
CA	1	1,4%	7033	2384	2408	0	1	More than 2000 subsid, more than 1% GMIs
FR	1	0,6%	6607	1790	1712	0	0	
IL	1	0,7%	3454	878	999	0	0	
CH	1	0,9%	2989	1378	925	0	0	
IT	1	0,2%	2925	709	1175	0	0	
NL	1	0,5%	2814	927	795	0	0	
SE	1	0,6%	2759	764	689	0	0	
AU	1	0,5%	1623	552	761	0	0	
AT	1	0,5%	1499	565	463	0	0	
BE	1	0,3%	1481	749	491	0	0	
FI	1	0,3%	1382	313	344	0	0	
DK	1	0,3%	1159	334	378	0	0	
ES	1	0,2%	929	337	474	1	1	
IE	1	0,5%	689	403	219	0	0	
NO	1	0,2%	587	186	262	0	0	
NZ	1	0,3%	299	108	167	0	0	
CZ	1	0,1%	296	151	113	0	0	
MX	1	0,0%	284	136	143	1	1	
PL	1	0,1%	273	130	145	0	0	
HU	1	0,1%	185	99	75	0	0	
TR	1	0,1%	154	68	94	0	0	
GR	1	0,0%	100	49	57	0	0	
LU	1	0,5%	98	77	34	0	0	
PT	1	0,1%	87	38	67	1	1	
CL	1	0,3%	50	17	41	1	1	
SI	1	0,3%	45	14	32	0	0	
SK	1	0,0%	42	29	30	0	0	
EE	1	0,1%	37	19	21	0	0	
CO	1	0,1%	36	14	27	1	0	Less than 100 subsid and less than 0.2% GMIs
TU	1	0	0	0	0	1	0	Less than 100 subsid and less than 0.2% GMIs
VE	1	0	0	0	0	1	0	Less than 100 subsid and less than 0.2% GMIs
CN	0	3,8%	12163	2686	2488	1	1	
TW	0	2,0%	10526	1164	1771	1	1	
IN	0	0,8%	4232	2009	721	1	1	
SG	0	0,5%	1131	512	286	0	0	
HK	0	0,8%	561	209	255	0	0	
RU	0	0,1%	537	263	216	0	0	
BR	0	0,1%	413	194	196	1	1	
SA	0	0,7%	372	94	36	0	0	
MY	0	0,2%	314	151	105	0	0	
ZA	0	0,3%	171	68	87	0	0	
TH	0	0,1%	124	64	68	1	0	Less than 100 subsid and less than 0.2% GMIs
RO	0	0,1%	108	62	43	0	0	
AR	0	0,1%	90	56	56	1	0	Less than 100 subsid and less than 0.2% GMIs
PH	0	0,2%	73	44	36	1	1	
UA	0	0,1%	72	42	38	0	0	
AE	0	0,2%	68	37	37	0	0	
EG	0	0,0%	50	33	26	0	0	
BG	0	0,1%	45	23	24	0	0	

Sample of countries with at least 20 subsidiaries patenting on average between 2010 and 2015. BFF indicates the list of , while BCSS indicates our list. OECD indicates whether the country is a member of the OECD.

C.2 Construction of a Database of Migration Reforms

Collecting Reforms

In constructing a sample of reforms, our starting point was the work of Branstetter, Fisman and Foley (2006), who indexed global intellectual property reforms. The countries indexed in the final dataset are: Brazil, Canada, Chile, China, Germany, India, Japan, Mexico, the Philippines, Portugal, South Korea, Spain, Taiwan, the United Kingdom, and the United States. We selected countries based on the presence of: (a) historical enactment of intellectual property legislation supportive of patenting; (b) multinational activity; and (c) significant migration flows. Ten of these countries coincide with the sample analyzed in Branstetter, Fisman and Foley (2006), who studied the impact of systematic reforms designed to strengthen and standardize intellectual property on MNEs' resulting foreign direct investments from 1982 to 1999. Relative to that study, we expanded the sample to five additional countries with the aim of including countries that are the source and destination of significant migration flows. For instance, Canada and the United Kingdom were in the top four most frequent destinations of OECD migration in 2010, while India, the Philippines, and the United Kingdom experienced the most net emigration in 2010 (Kerr et al., 2016). Additionally, several of the countries in the list are representative of high levels of net inventor immigration.

After identifying a list of countries, we turned to collecting reforms. During the period of 2017 through summer 2020, teams of research assistants and the authors identified migration policy reform events impacting high-skilled human capital migration of two types into a focal country: (a) return migrants and (b) foreign immigrants. Alongside identification, the team collected corresponding primary and secondary sources related to reforms. Collection occurred in three waves—the first in 2017, the second in Winter 2018 to Summer 2019, and the third in Summer 2020. The latter two focused on ensuring a complete collection of reforms enacted in the period of 1990 to 2016. When we identified additional reforms outside this period, we included them in the dataset. As a result, the database of reforms is primarily useful for analyses on the post-1990s

Table C11: Example Keyword Terms Leveraged in Search

Wikipedia	Google: HS HC	Google: Catch-All
1. Migration in <Country>	1. Entrepreneurship Immigration <Country>	1. Move to <Country>
2. History of Migration in <Country>	2. Start a Business as an Immigrant <Country>	2. Immigrate to <Country>
3. Migration Policy <Country>	3. STEM Incentives <Country>	3. Immigration to <Country> <Nationality> Heritage
4. <Nationality> Citizenship	4. High Skill Migration <Country>	4. Migration Policy <Country>
5. Citizenship in <Country>	5. Refugee Immigration <Country>	5. History of Migration <Country>

era and is less reliable for reforms and initiatives prior to this point.

Starting from the second wave, we began collecting reforms following a standardized heuristic with emphasis on ensuring completeness in the dataset. First, we conducted a search to collect any primary or secondary news sources related to the countries under review from websites that focused on information related to migration policies and programs of countries, including websites focused on assisting immigration and websites focused on navigating migratory legislative policies of countries. Example websites include: LegislateOnline, (http://www.legislationline.org/); the Library of Congress, (https://www.loc.gov/law/help/migration-citizenship/); and that of the think tank Migration Policy (http://www.migrationpolicy.org). Website-based searches would also turn to legal codes of countries published online by their central governments; we searched explicitly for links and connections to the codified migration laws of a country (e.g., legal codes of all European Union countries are indexed on EU websites). After website searches, we searched academic repositories for articles with comprehensive explanation of migration policy reforms and initiatives. Finally, these searches were followed by a series of keyword-based searches implemented in the Wikipedia online encyclopedia (https://www.wikipedia.org/) and Google's web search engine focused on identifying articles, information, and primary sources related to migration policy reforms, migration policy initiatives, and high-skilled human capital immigration into and out of a country. Iteration between approaches occurred as necessary (for example, if Wikipedia revealed several individual laws or programs to search for, the researcher would spend time looking for primary sources for those laws or programs in legal code and government websites). Table C11 provides a list of example searches utilized in the search process.

Categorizing Reforms

To characterize the anticipated impacts of reforms, the authors qualitatively assessed each reform and its associated primary and secondary sources. Based on this analysis, reforms were coded according to whether the anticipated effects were positive (easing movement) or negative (restricting movement) based on how the reforms impacted legal migration frameworks of countries. Specifically, reforms were classified as positive or negative according to anticipated impact along three dimensions: (a) the rights of a migrant (either foreigners or returnees); (b) the expected volume of migrants post reform; and/or (c) the duration of stay or required time to achieve residency status criteria associated with admission to a country. Reforms identified as generating increases (alt. decreases) along any of these dimensions were then codified as having a positive (alt. negative) effect. While rare, some reform packages simultaneously enacted provisions exhibiting both positive and negative effects. For such reform events, we treated the event as an instance of both a positive reform and a negative reform. For example, in 2006, the U.K. enacted administrative regulations that increased the number of visas awarded, which increased work rights for migrants with accepted visas, but also decreased rights for those who encountered visa refusals (limitation of rights to appeal). As a result, this reform is coded both as a positive and negative reform event for the United Kingdom in 2006.

Table C12 considers the subsample of all reforms affecting workers' migration and presents how each of them is classified across the three main dimensions considered in the heterogeneity analysis: i) Volume versus rights, which determines whether the reform operates through a change in quotas or a change in the rights granted to migrants in the host country. ii) Major versus minor, which evaluates the importance of the change in determining migration flows. iii) Permanent versus temporary, which distinguishes between legal changes affecting stays of more or less than one year. Here we include only the reforms taking place during the years 1990 to 2016, which correspond to the period analyzed in this paper. Most countries in our sample have at least three reforms within the 26 years, while some countries (such as China, Japan, and South Korea) have five or more. A large majority of reforms—85%—target foreigners, while only 15% explicitly target

Table C12: Classification of reforms

Country	Year	Type	Volume	Rights	Major	Minor	Permanent	Temporary
BR	2014	positive	1	1	0	1	0	1
CA	2002	negative	0	1	1	0	1	0
CL	2005	positive	0	1	0	1	1	0
CN	1994	positive	1	0	0	1	1	0
CN	1996	negative	0	1	1	0	1	0
CN	2004	positive	1	0	0	1	1	0
CN	2008	positive	1	0	1	0	1	0
CN	2013	positive	1	0	0	1	1	0
DE	2000	positive	1	0	0	1	0	1
DE	2005	positive	1	1	1	0	1	0
DE	2012	positive	1	0	0	1	1	0
DE	2016	positive	0	1	0	1	1	0
ES	1996	positive	0	1	1	0	1	0
ES	2003	positive	1	1	1	0	1	0
ES	2009	positive	0	1	0	1	1	0
GB	1996	negative	0	1	0	1	1	0
GB	2006	positive, negative	0	1	1	0	1	0
IN	2005	positive	1	0	0	1	1	0
IN	2016	positive	1	0	0	1	0	1
JP	1992	positive	1	0	0	1	1	0
JP	1993	positive	1	0	1	0	1	0
JP	2010	positive	0	1	1	0	1	0
JP	2012	positive	1	0	1	0	1	0
JP	2014	positive	1	0	0	1	1	0
JP	2015	positive	1	0	1	0	0	1
KR	1991	positive	1	0	0	1	0	1
KR	1992	positive	1	0	0	1	0	1
KR	1993	positive	1	0	1	0	0	1
KR	1994	positive	1	0	1	0	0	1
KR	1995	positive	0	1	0	1	1	0
KR	1996	positive	1	0	1	0	0	1
KR	1998	positive	1	1	0	1	1	0
KR	1999	positive	1	1	1	0	0	1
KR	2002	positive	1	0	0	1	0	1
KR	2004	positive	1	0	0	1	0	1
KR	2007	positive	1	0	1	0	0	1
KR	2009	positive	1	1	1	0	1	0
KR	2010	positive	1	1	1	0	1	0
MX	2010	positive	0	1	0	1	1	0
MX	2011	positive	0	1	1	0	1	0
MX	2012	negative	0	1	1	0	0	1
MX	2014	positive	1	0	0	1	1	0
PH	1996	positive	1	0	1	0	1	0
PH	2002	positive	1	1	1	0	0	1
PH	2009	negative	1	0	1	0	1	0
PH	2012	negative	1	0	0	1	1	0
PH	2013	positive	1	0	0	1	0	1
PH	2015	negative	1	0	0	1	1	0
PT	2001	positive	1	0	1	0	1	0
PT	2003	negative	1	0	1	0	1	0
PT	2012	positive	1	0	0	1	0	1
TW	1992	negative	1	1	0	1	0	1
TW	2014	positive	1	1	1	0	1	0
TW	2015	positive	1	0	1	0	1	0
US	1990	positive	1	0	0	1	1	0
US	1998	positive	1	0	1	0	1	0
US	2000	positive	1	0	1	0	1	0
US	2004	negative	1	0	1	0	1	0
US	2009	negative	1	0	0	1	1	0
US	2015	positive	0	1	0	1	1	0

returnee migrants. Reforms during the period leaned toward positive interventions, anticipated to increase migration, with 48 identified instances of anticipated positive effects, one identified instance where the outcome is ambiguous because the new legislation includes both positive and negative aspects, and only 12 with anticipated negative effects. In our complete dataset, we also collected reforms affecting student migrants or entrepreneurs. More details are available upon request.

D Estimation of Treatment Effects Give Frequently Repeated and Clustered Events

D.1 A Generalized Estimator

In a classical difference-in-differences or event-based approach, the key term of interest is an indicator variable or series of relative event-time indicators that take the value 1 in the periods of and subsequent to treatment. The coefficient on this key term estimates the mean difference in the response in the period(s) surrounding treatment with emphasis on those subsequent to treatment.[40] This model is inflexible in the case of repeated treatment, and standard practice is to discard observations where repeated treatment occurs. This is not feasible in all situations, however, including those where treatment events are clustered at the level of the group among observations with few group categories or where treatment events are clustered in time, as in our data.

To accommodate our setting, we relax the requirement that the time periods examined in the difference-in-differences estimator include only the singular enactment of an event; we treat the difference-in-differences estimator key term as a non-negative count of events enacted that can vary over time. Generalizing from the regressions in our analyses, we allow variations on models of the general form:

$$Y_{it} = f(\gamma_i + \gamma_t + \beta\ r_{it};\ \epsilon_{it}),$$

where Y_{it} represents the response variable in time t for observation group i, γ indexes time and group fixed effects, and r_{it} is the count of treatment events implemented to date for group i in

[40] Borusyak and Jaravel (2017) present canonical equations that outline the generalized event-based estimator and relate difference-in-differences specifications to event-study specifications by demonstrating that the estimator is a specific case of a more general event-study specification with dynamic treatment effects. Goodman-Bacon (2021) examines the case of difference-in-differences estimation conditional on variation in treatment timing. This author shows that the treatment effect estimated is a weighted average of the treatment effect of the component difference-in-differences estimates and proposes a test for the validity of such estimators.

time t, and ϵ_{it} is the standard error term.[41] This model is equivalent to classical difference-in-differences or event-based approaches that include fixed effects that subsume the independent effects of time and treatment.

In this model, the key coefficient of interest is β, and it is interpreted as the average post-period increase in the response conditional on an additional event. For simplicity, the measurement r_{it} assigns equal weight to each consecutive reform of the same type and, as a result, imposes the restriction that the average treatment effects of a given reform event type must be equivalent across reform events.

A generalized version of this measure might estimate treatment effects independently, including linearly additive indicators for each level of consecutive treatment such that $r_{it} = \sum_j^J \sum_{t=0}^{T=t} \mathbb{1}(event_{it,j})$, where j indexes the various levels of treatment and where coefficients are estimated for each level of j. To economize on statistical power and maintain simplicity, we impose the restriction of equivalence in effect across treatment levels in our analyses.

Causal inference given this estimator requires additional assumptions. The literature on causal inference in the presence of repeat events (e.g., Blackwell (2013)) suggests two. First, it is necessary to assume that treatment events are linearly additive in their effects and exhibit independence, such that there is no interaction across treatment levels. Second, it also must be assumed that treatment is orthogonal to the consequences of the treated unit's prior treatment history—i.e., future treatment and impacts on the response are not significantly determined by the prior sequence of past treatment.

D.2 Simulation of Estimator Measurement Error

To evaluate whether this estimator accurately measures the corresponding causal treatment effect, we conducted computational simulations in which data based on parameters in our setting were simulated, and the model fit repeatedly across several simulations. Specifically, for each simu-

[41] In other words, $r_{it} = \sum_{t=0}^{T=t} \mathbb{1}(event_{it})$.

lation s, data were generated from the following process involving "Reform Events" across eight years (y) affecting 15 "Countries" (c) and 10 "Firms' (f) present within those countries (where other parameters were chosen to approximate sample means in the actual data observed where possible[42]):

1. **Simulate Country Treatment Pathways:** A treatment event pathway was assigned for each simulated country with random variation in the frequency of treatment events within a given country that was defined by random variation in the probability of treatment event occurrence across countries. This occurred in two steps:
   (a) **Assign Random Country-Level Probability of Per-Year Treatment From Uniform Distribution:** $p_{cs} \sim \mathcal{U}(0, 0.4)$
   (b) **Determine Treatment Pathway From Binomial Distribution:** $T_{cys} \sim \mathcal{B}(p_{cs})$
2. **Simulate One-Way Fixed Effects:**
   (a) **Simulate Assignee Fixed Effects:** $\gamma_{fs} \sim \mathcal{N}(\mu = 10, \sigma = 3)$
   (b) **Simulate Year Fixed Effects:** $\gamma_{ys} \sim \mathcal{N}(\mu = 0, \sigma = 3)$
   (c) **Simulate Country Fixed Effects:** $\gamma_{cs} \sim \mathcal{N}(\mu = 0, \sigma = 3)$
3. **Simulate Two-Way Fixed Effects:**
   (a) **Simulate Assignee-Year Fixed Effects:** $\gamma_{fys} \sim \mathcal{N}(\mu = 0, \sigma = 3)$
   (b) **Simulate Country-Year Fixed Effects:** $\gamma_{cys} \sim \mathcal{N}(\mu = 0, \sigma = 3)$
   (c) **Simulate Subsidiary (Assignee-Country) Fixed Effects:** $\gamma_{fcs} \sim \mathcal{N}(\mu = 0, \sigma = 3)$
4. **Simulate Random Noise:** $\epsilon_{fcys} \sim \mathcal{N}(\mu = 0, \sigma = 1)$
5. **Simulate Treatment Effect w/Random Variance Across the Year-Firm-Country Level:** $D_{fcys} \sim \mathcal{N}(\mu = 3, \sigma = 1)$

[42]While fixed effects are estimates from a consistent normal distribution, the results prove robust to estimating fixed effects based on by-variable mean and standard deviation point estimates from a regression on the data that includes only fixed-effect terms.

6. **Compute Linearly Additive Response Based on Differing Treatment Modes:**

   (a) **Treatment Affects Rate:** $y_{fcps} = \gamma_{fs} + \gamma_{cs} + \gamma_{ys} + \gamma_{fcs} + \gamma_{fys} + \gamma_{cys} + \sum_{t=0}^{T=t}(T_{cys}) \times D_{fcys} + \epsilon_{fcys}$

   (b) **Treatment Affects Level:** $y_{fcps} = \gamma_{fs} + \gamma_{cs} + \gamma_{ys} + \gamma_{fcs} + \gamma_{fys} + \gamma_{cys} + T_{cys} \times D_{fcys} + \epsilon_{fcys}$

For each of the 5,000 simulations, we then fit the following regressions:

$$y_{fcps} = \gamma_{fs} + \gamma_{cs} + \gamma_{ys} + \beta r_{cys} + \epsilon_{fcys} \qquad \text{Cumulative Estimator}$$

$$y_{fcps} = \gamma_{fs} + \gamma_{cs} + \gamma_{ys} + \beta T_{cys} + \epsilon_{fcys}, \qquad \text{Panel Estimator}$$

where the first equation corresponds to estimating the treatment effect on the cumulative count of events and the second equation corresponds to a panel estimator where the variable of interest takes the value 1 in periods where the event occurs and 0 otherwise. For the resulting key coefficient of interest (β), we calculated the variance of the resulting estimates and their mean squared error defined as the mean of the square of the differences between the estimate and the actual treatment effect (MSE $= \frac{1}{5{,}000}\sum(3-\beta)^2$).

Table D13: Efficiency of Estimator

Model	Estimator	$\mu(\beta)$	Var.(β)	MSE	$\frac{MSE}{TreatEffect}$	$\frac{Var.(\beta)}{TreatEffect}$
Rate	Cumulative	3.006	0.349	0.349	0.116	0.116
Rate	Panel	1.475	0.794	3.120	1.040	0.265
Level	Cumulative	0.783	0.406	5.319	1.773	0.135
Level	Panel	2.984	0.688	0.688	0.229	0.229

Notes: This table provides the results from simulations designed to evaluate the efficiency of the "cumulative events" estimator.

Table D13 displays the resulting estimates. It is readily apparent that the panel estimator is best suited for contexts where treatment produces a single-period shock to the response; and in such cases, it estimates closely the real average treatment effect. However, in the case of repeated events, the cumulative estimator most closely reflects the real average treatment effect. Additionally, when applied to the outcome derived from a model in which treatment influences the rate of the response, the cumulative estimator yields the lowest variance in the estimates as well as the lowest mean squared error across all specifications. Overall, we interpret this as strong evidence for the statistical validity of the cumulative estimator.