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DISCUSSION PAPER

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# Global Influence of Inventions and Technology Sovereignty

# Global Influence of Inventions and Technology Sovereignty

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**Abstract**

We analyze the technology sovereignty of Europe, the US, China, Japan, and Korea, representing the world's leading innovators. By examining citations from the universe of PCT patent applications between 2000 and 2020, we determine the strength and direction of inventions' influence at global and bilateral levels to assess each geographic area's technology sovereignty. The US shows superior technology sovereignty through its leadership in global and bilateral influence. While the US and Europe are highly integrated, their global positions differ as Europe depends on all geographic areas except China. Although China has filed the most patent applications in recent years, bilaterally it remains dependent on all other geographic areas. Moreover, only Japan and Korea show a recent decline in their global influence, despite previously holding a leading position.

**Keywords**: technology sovereignty, global influence of inventions, geographic areas, bilateral influence, patent citations
**JEL Codes**: O33, O34

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# 1 Introduction

The global economic landscape has fundamentally shifted from the paradigm of globalization to renewed concern regarding the risks and rewards of economic interdependence. This shift has sparked critical discussion of technology sovereignty, a concept at the crossroads of geoeconomics and innovation studies. Technology sovereignty differs from national autarky or technological self-sufficiency. It refers to a country's capacity to provide essential technologies for its competitiveness and welfare, and to develop them domestically or acquire them from abroad without being unilaterally dependent on any particular country (Edler et al. 2023). Since new innovations and technological regimes develop globally, technology sovereignty and international cooperation are not antagonistic, but mutually dependent. However, if there is no reciprocal interdependence ensuring access to foreign knowledge, unilateral structural dependence can erode the technology sovereignty of the more dependent country.

Recent technological competition and geoeconomic disputes, particularly between China and the West (Lee 2021), have compelled policymakers to balance efficiency and risk reduction strategies. In general, countries aim to collaborate with like-minded and geoeconomically reliable partners while reducing unilateral dependence on less reliable countries. Therefore, it is increasingly necessary for policymakers to develop measures of economic influence and dependence that allow for evidence-based decision making. Because understanding the bidirectional nature of knowledge flows is essential, this requires increasingly nuanced measures to assess how countries mutually influence one another's innovations. This study presents a novel empirical approach to measure the influence and dependence of the leading global innovation regions, rendering the concept of technology sovereignty empirically assessable.

From an empirical perspective, the prior literature has mainly focused on onedirectional knowledge flows, i.e. this literature has only considered the extent to which a country benefits from the knowledge generated in other countries (e.g. see Eaton and Kortum (1999); Liu and Ma (2023); Melitz and Redding (2022)). To extend this literature, we measure knowledge flows as bidirectional flows based on patent citations. In particular, we evaluate how two countries build on each other's inventions. Ensuring the comparability of the units of knowledge flow, i.e. citations, is crucial to netting out bilateral dependence and accurately measuring a country's technology sovereignty. This presents an empirical challenge due to considerable heterogeneity across national data generation processes, which is evident not only for patents but also for citations.

Building on an approach that was first presented by Boeing and Mueller (2016), we ensure the comparability of the data generation process of patent applications and citations. This is achieved by restricting to patent applications filed through the World Intellectual Property Organization's (WIPO) Patent Cooperation Treaty (PCT), and citations generated in the corresponding international search reports (ISRs) during the international phase of PCT applications. In measuring global influence, we consider only nonself-citations from foreign sources and are interested in the extent to which inventions in one geographic area provide the basis for inventions in other areas.[1] This approach also ensures that our measures are unbiased and independent of potential domestic policy distortions.

We contribute to the existing literature by introducing empirical measures of technology sovereignty. Our analysis is based on the entire universe of global PCT filings between 2000 and 2020. In line with the focus of our study, we initially allocate all applications to one of the top four global innovation regions: Europe, the United States (US), China, Japan and Korea, along with a residual category (covering the residual countries). Subsequently, we compute the number of citations that a geographic area obtains from another area – and vice versa. In our empirical analysis, we examine three important aspects. First, we analyze the strength of global influence at the patent level for each geographic area, and provide rigerous validation of our measure. Second, we explore the geographic direction of global influence and how it changes over time. Third, to calculate bilateral influence, we add up all inventions from a geographic area during a specific timeframe and determine if the focal area shows reciprocal dependence on other areas or whether its situation is characterized by either independence or dependence. We additionally compute the average bilateral influence for each geographic area in comparison to all others and again analyze changes over time.

Throughout our findings, it is clear that the US has maintained its influential position as the world's technological superpower. Not only does the US possess the strongest global influence, but it also exceeds all other countries in its respective bilateral relationships, thereby establishing remarkable technology sovereignty. Nevertheless, this conclusion is far from obvious when looking at simple patent counts. Since 2019, China surpassed the leading countries US, Japan, Korea, and Germany in PCT patent applications, making it the top-ranking country. However, based on our analysis, China's innovation policy emphasizing quantitative patent targets, in conjunction with industrial and R&D policies and periodic moonshot projects, has not yet resulted in inventions with overwhelming global influence. On the contrary, our research shows that China is dependent on all other geographic areas, and this dependence is evident on average across all technologies, as well as when considering specifically future-oriented key enabling technologies (KETs).

Another important insight is the strong integration between the US and Europe

[1] The term "geographic area" refers to (i) Europe, (ii) the United States, (iii) China, (iv) Japan and Korea, and the category of residual countries. While some geographic areas include only one country, others include more than one.

in terms of the direction of global influence. In comparison to this high degree of integration in the West, East Asian countries show a growing internal focus over time. This is the case not only in China, where innovation policy is explicitly aimed at reducing foreign dependence, but also in Japan and Korea. Strikingly, Japan and Korea have witnessed a recent decrease in their average bilateral influence, despite previously holding the highest position, thus making them the only geographic region exhibiting a downward trend. In contrast, Europe, the US, and China are able to improve their positions. The cases of China (for all PCT applications) as well as Japan and Korea (for KET PCT applications) also show that leadership in application numbers does not necessarily equate to a higher technological influence. For example, while Europe files a relatively lower quantity of PCT applications in KETs, its respective influence is actually stronger than in overall technologies.

There are various considerations relevant to policymakers. While Western geographic areas remain stable and integrated amidst a changing global geoeconomic landscape, the US and Europe differ considerably in their respective positions. The US has achieved outstanding technology sovereignty, while Europe is dependent on all geographic areas except China. Thus, European policymakers should address this dependency, possibly by leveraging Europe's relative advantage in KETs, while avoiding any shift from independence to dependence on Chinese innovation.

Although Japan and Korea carry significant global influence and depend solely on the US, this geographic area has recently experienced a gradual decline, albeit from a high level. While Japan and Korea have made significant contributions to global innovation for several decades, and are also heavily involved in future-oriented innovation related to KETs, this inventive activity has not been adequately translated into international influence. Inventions from Japan and Korea receive less foreign citations over time, not just from fewer geographic and technology areas, resulting in a decline in their overall influence. It is crucial for policymakers to address this downward trend. Finally, Chinese policymakers face a challenging situation. Other countries, due to systemic rivalry that is at least partly attributable to China, are seeking long-term technology sovereignty that goes beyond recent de-risking strategies in commodity trade and foreign direct investment. However, such circumstances pose a challenge for China, as it has made significant progress in both the number and influence of inventions, but remains more dependent on other geographic areas than vice versa.

It it is important to point out that political requirements for reciprocity and redundancy will inevitably reduce economic efficiency. While complete global integration seems not to be the order of the day, collaboration among like-minded and geoeconomically reliable partners still allows countries to benefit from their inclusion in the global innovation network. However, cooperation with less reliable countries should be embedded in a setting of at least reciprocal bilateral dependence, while actively reducing unilateral dependence but building up inventive capacity domestically or among reliable partners.

The paper proceeds as follows. Section 2 reviews the literature on technology sovereignty, patent citations, and global influence of inventions. Section 3 introduces data and measurement. Section 4 presents the empirical results, while section 5 discusses policy implications. Section 6 concludes.

# 2 Literature

## 2.1 Technology sovereignty

In recent years, the global economic order has undergone a fundamental transformation. The paradigm of globalization has given way to new perspectives regarding the risks and benefits of economic interdependence. The world is shifting away from a market-based regime in which economic integration was seen as an end in itself to one in which strategic actors exploit economic openness and vulnerabilities to pursue independent geopolitical objectives. In response, governments are attempting to make their economies more resilient. Policymakers increasingly require measures of economic impact and dependency to make informed, evidence-based decisions. Located at the intersection of geoeconomics and innovation studies, the concept of technology sovereignty has received considerable attention; however, empirical measures related to technology sovereignty are urgently needed to advance such evidence-based policymaking.

According to March and Schieferdecker (2023), technology sovereignty is distinct from national autarky or technological self-sufficiency. The authors define technology sovereignty as a country's capability to self-determine the development and use of technologies and innovations that affect its political and economic sovereignty. Similarly, Edler et al. (2023) define technology sovereignty as the capability to offer the necessary technologies for the competitiveness and welfare of a country and to develop or acquire them from other geographic areas without being unilaterally dependent on a particular source.

Hence, access to the outcomes of research and development (R&D) that is conducted domestically and internationally has a crucial role in establishing technology sovereignty. Since new innovations and technological regimes develop globally, technology sovereignty and international cooperation are not antagonistic, but mutually dependent. As documented in Griffith et al. (2004), domestic R&D serves at least two functions from this perspective. First, it facilitates the identification and adoption of R&D outcomes from international sources, which is also referred to as absorptive capacity (Cohen and Levinthal 1989). Second, it is essential for generating research outcomes that other international actors can use and build upon. Overall, domestic R&D is crucial for benefiting from international knowledge and avoiding unilateral dependence.

Within the concept of technology sovereignty, so-called key enabling technologies (KETs) play a crucial role in contributing to economic growth and development while also promoting dynamic application of other technologies. KETs exhibit three defining features (Commission of Experts for Research and Innovation (EFI) 2022). (1) They have various applications in different technological fields and economic sectors. (2) They exhibit strong, non-substitutable complementarity with multiple other technologies. (3) Both the KET itself and its application areas have a high potential for performance enhancement. Interpreted from a global perspective, economies could specialize in specific KET areas and develop comparative advantages over other economies. This portfolio perspective suggests that economies may specialize in certain KETs, leading to mutual dependence on one another, which makes unilateral dependence less probable. From a development perspective, economies that are catching up may benefit more from pursuing long-term rather than short-term innovation strategies (Lee 2021). For example, such economies can focus on certain KETs that require more substantial upfront investments but will enhance comparative advantage and technology sovereignty in the future. This approach still emphasizes the importance of global integration, which significantly differs from technological self-sufficiency strategies.

However, in the absence of reciprocal interdependence ensuring access to foreign knowledge, unilateral structural dependence can erode the more dependent country's technology sovereignty; therefore, a country's strategic placement between complete global integration and national self-sufficiency is crucial to defining the limits of reliance and autonomy (Eaton and Kortum 1999). Recent technological competition and geoeconomic disputes, particularly between the US and China, but also between Europe and China, compelled a balancing act between prioritizing efficiency and implementing risk mitigation strategies, which could also necessitate the development of domestic redundancy. Overall, policymakers are now attempting to transition collaborations toward like-minded and geoeconomically reliable partners, while seeking to reduce unilateral dependence on less reliable countries. At the global level, this involves navigating technological influence and dependence among countries and regions (Van der Pol and Virapin 2022).

Notably, technology sovereignty is distinct from the interdependencies between countries that can be observed through commodity trade; for example, when considering global value chains (Felbermayr et al. 2023). The flow of commodities represents trade in semi-finished or finished products, whereas the production of knowledge precedes that of commodities and is often an early determinant of subsequent product specialization. Against this background, we are particularly interested in examining the degree to which the knowledge of one country or region is taken up elsewhere. In this sense, both phenomena are related but distinct. For instance, Gong et al. (2023) investigate the patenting and exporting activities of Chinese firms in the US, determining that the first US patent grant has a positive impact on the Chinese companies' subsequent export performance, demonstrating that knowledge creation and the protection of inventions precede the production and shipment of goods. Similarly, Liu and Ma (2023) measure the correlation between knowledge flows and input-output production networks across industries in 40 countries, revealing these activities are only moderately correlated. Specifically, knowledge spillover from upstream industries is more influential than that from within a given industry or this industy's international commodity trade to advance innovation in the focal industry. Han et al. (2023) show that domestic upstream innovation is important for counteracting negative sanction-induced shocks to a downstream industry because it is possible to substitute the required intermediates through domestic production. In general, upstream innovation capacity is crucial for mitigating downstream geoeconomic risks. It follows that KETs, which are often in upstream sectors, are of considerable strategic importance.

Our work is also related to the previous literature on knowledge spillovers. This literature attests to the longstanding acknowledgment that inventions do not just take place within national boundaries but are dependent on knowledge flow from abroad. Prior research shows that such knowledge spillovers can directly affect countries' productivity and output growth (Melitz and Redding 2022). Whereas the literature on knowledge spillover concerns access to international knowledge and its economic consequences, our study is interested in measuring the influence that the inventions of one geographic area have on those of other areas. From an empirical perspective, previous research on knowledge spillovers primarily focuses on onedirectional knowledge flows, only considering the extent to which one country benefits from the knowledge generated by other countries. More specifically, a country's patent citations of inventions from other countries are a measure of the latter countries' technological influence in the first country (Aghion et al. 2023). We extend this approach by measuring knowledge flows as bidirectional by examining patent citations to measure how a pair of countries builds on one another's inventions. Importantly, ensuring comparability between the units of knowledge flow (citations) is crucial for determining bilateral dependence and accurately measuring countries' technology sovereignty. This endeavor poses an empirical challenge due to considerable heterogeneity across national data-generating processes, which is true for patents and citations. The next section elaborates on the issues surrounding the use of citations in cross-country analyses and our approach to addressing them.

## 2.2 Citation-based measures

Forward citations of a published patent are a well-established measure of the cumulative nature of inventions (Jaffe et al. 1993). This measure is observable since subsequently filed patents refer to prior art (Higham et al. 2021). As such, forward citations are an appropriate measure for the global influence of inventions, and are often used to measure economic value (Harhoff et al. 1999; Lanjouw and Schankerman 2004). Gambardella et al. (2008) show that forward citations have a closer relationship to patents' actual economic value than references, claims, or family size. Moreover, variation in forward citations is used to account for other margins of patent heterogeneity (see the survey by Jaffe and De Rassenfosse (2017)), including technical value (Trajtenberg 1990) and technological influence (Corredoira and Banerjee 2015). Recent studies also use citations in network settings, going beyond measuring knowledge flow between two patents. For example, citations are used to examine the diffusion of knowledge (Rosell and Agrawal 2009) or to determine centrality of specific patents (Funk and Owen-Smith 2017; Park et al. 2023). Nevertheless, working with citation data is subject to empirical challenges as it is necessary to control for multiple, unrelated changes in patent and citation data-generating processes to obtain unbiased estimates of economic phenomena. To address these challenges, Kuhn et al. (2020) recommend selecting appropriate patent and citation types and employing a fixed effects approach to control for remaining differences (e.g., across technology areas and time) in the patenting process.

A well-known challenge to using forward citations is their application to cross-country comparisons. This is because heterogeneity across the legal frameworks of national patent examination leads to significant variation in forward citations generated across patent offices. For a set of triadic patent families following national standards, Michel and Bettels (2001) show that the US Patent and Trademark Office (USPTO) applies three-times more patent references than the European Patent Office (EPO) and patent examiners are more likely to cite domestic patents, which is also known as "home bias" (Bacchiocchi and Montobbio 2010). Thus, naïve comparisons of international citation measures across (and within) countries may be biased. When examining international knowledge flows, some studies have avoided citations and instead relied on counting patent applications by foreign applicants (Eaton and Kortum 1999) or international co-applicants (De Rassenfosse and Seliger 2020).

Although foreign filings tend to be a positive and more homogeneous selection compared with domestic filings because it is more costly to file in more than one patent office, considerable heterogeneity remains within selected samples. To address this issue, several studies have used forward citations while attempting to control for potential differences in the data-generating process. A typical approach restricts the data-generating process of citations to a single patent office. For example, the studies by Lee and Yoon (2010) and Wu and Mathews (2012) compare forward citations received by USPTO applications filed by applicants from the US, Japan, Korea, and Taiwan. While focusing on a single patent office can increase the comparability of the citations generated, allocation of these citations may still be subject to the aforementioned home bias, favoring US patents, while those of other countries represent a positive selection. Another obvious limitation of this approach is its narrow focus on patenting in one country, which limits its global relevance (De Rassenfosse et al. 2014).

Another set of studies investigating international knowledge flows increases the number of analyzed countries but faces the limitation of differing data-generating processes for patents and citations across countries.[2] Examining 40 major countries between 1976 and 2020, Liu and Ma (2023) investigate whether patents filed in a given country cite other patents filed in that country or abroad. Patents are either assigned by the country of inventors, applicants, or patent office (in that order). As an invention can generate patent applications in more than one country, all related patents are grouped by patent family and the information is attributed to the priority application. Eugster et al. (2022) introduce further refinements by only selecting patent families with a minimum of two national applications, for which the country is identified according to the address of the first inventor, and excluding self-citations between patents with the same inventors.[3] The citation window, referring to the time period in which a cited patent can receive citations from a citing patent, is set to four years after the publication of the cited patent.[4] While excluding most recent years from the analysis due to truncation issues, this practice ensures comparability between patents filed at different points in time.[5]

The rise of China has significantly contributed to global patenting activities; however, numerous propatent policies have also led to an increase in marginal patents and related citations. While China is globally leading in terms of patent

[2] A well-documented historical example is Japan's single-claim patent before 1989 (Goto and Motohashi 2007). Although the introduction of multiclaim patents and more stringent selection criteria in patent applications reduced the number of patents (Motohashi 2004)), ceteris paribus, such patterns may have some persistence over time. Additional differences between patent offices include divergent rules for applicant citations. Whereas in the US the applicant needs to provide references to all relevant prior art that they are aware of, the EPO requires only the examiner and not the applicant to provide references to prior art (Michel and Bettels 2001).

[3] Self-citations account for about 10% of citations received (Higham et al. 2021). The exclusion of self-citations is a common practice because larger firms typically have more patents from which to potentially cite their own prior art. To address this concern, it is instrumental to define self-citations at the applicant level rather than the inventor level.

[4] Previous research shows that patents reach the highest probability of citation around three years after publication (Hall et al. 2005).

[5] Typically, patents are recorded by their priority date and publication occurs after 18 months, marking the opening of the citation window. For example, a three-year citation window allows for analysis of patents that were filed four and a half years prior.

output in both national applications by residents and PCT applications since 2011 and 2019 (WIPO 2023), respectively, in 2020 Chinese examiners were handling 47% more patents than examiners in the US and 136% more than those in Europe (Branstetter et al. 2023; Yin and Sun 2023). Excessive workload, reduced examination time, and low salaries for examiners[6] can potentially degrade the quality of examinations, subsequently introducing measurement error regarding the citations made by such patents (Branstetter et al. 2023).

Citation data from China's patent office have only recently become available; however, national patenting targets (Sun et al. 2021), subsidies (Branstetter et al. 2023), and tax cuts (Wei et al. 2023) have all contributed to distorted patenting activities, which makes the interpretation of citations emanating from the Chinese patent office more difficult. Several studies substantiate this concern by relating citations to economic measures. For example, Yin and Sun (2023) show that forward citations are not correlated with initial patent auction prices in China, which contradicts results in other countries. Wu et al. (2022) only find a significant relationship between patent citations and firms' total factor productivity after restricting their sample to patents that incurred higher filing costs because they exceeded the threshold of 10 claims. Boeing and Mueller (2019) restrict their analysis to citations generated by ISRs of PCT applications. Investigating the correlation between R&D expenditure and citation-weighted patents, the authors find that only foreign citations, but not domestic and self-citations (which may be partially policy-driven), have a significant and positive relationship with R&D stocks in China. Referencing Germany as a country without domestic policy support for patenting, they show that all three citation measures have the expected positive correlation with R&D inputs. Taking a broader international perspective, Schmoch and Gehrke (2022) compare non-Chinese and Chinese PCT applications and demonstrate that subsequent to the international phase, 79% of non-Chinese applications are transferred to the national phase (in patent families with three or more national applications), whereas the corresponding rate for China is only 66%. This indicates lower average patent value, which is associated with China's subsidies and targets related to PCT applications.

Despite heterogeneity in the data-generating process of forward citations across national patent offices, some studies use forward citations in international comparison. Han et al. (2023) observe patents filed in the US that cite patents filed in China and vice versa, to measure decoupling and dependence. Bergeaud and Verluise (2022) divide global patenting activity into five geographic areas to investigate the rise of China in terms of six frontier technologies. In the most conservative analytical setting, they observe forward citations originating in PCT applications and received by the top 10% most cited (overall) patents in each technology, year, and

[6] Anecdotal evidence implies a monthly salary of around 10,000 RMB, which is equivalent to USD 1,600 (Branstetter et al. 2023).

country. While citations from PCT applications are a more homogeneous set, the mixture of citations generated in the international and subsequent national phase of the PCT process still introduces heterogeneity. Furthermore, the selection of cited patents is endogenous to the citation intensity of national processes.

To provide a rigorous assessment regarding the quality and global influence of inventions, analyses must consider differences in examination rules and types of patents filed. We follow Boeing and Mueller (2016) by including these aspects as, to the best of our knowledge, their approach provides the most rigorous setting for cross-country comparison of patent quality. The authors only examine PCT applications, which can make references or receive forward citation, and restrict such references (generated by ISRs) to foreign origin (i.e., the citing patent is abroad, while the cited patent is domestic), which also avoids potential upward bias in citations due to domestic policies, e.g. in China.

### 2.3 Global influence

The global influence of geographic areas can be measured in several ways. In this section, we first review literature that compares countries' innovative performance based on patent indicators. We then examine the bilateral influence between countries, as observed through patents and scientific publications, and finally consider the influence of policy on such relationships. At the most basic level, researchers have been interested in raw patent counts to measure influence. Traditionally, the US and Europe were the most significant patent applicants; however, they lost their leading position to East Asian countries in more recent years. In 2020, China filed 16.1% of global PCT applications (WIPO 2023), making it the world leader in patenting, followed by the US, Japan, Korea, and Germany. However, a simple comparison of patent counts, even if adjusted by conventional measures of patent quality, will most likely be misleading due to substantial heterogeneity across patents.

Addressing the concern of international comparability, Boeing and Mueller (2016) use foreign ISR citations, which are independent from domestic policy, to investigate the technological capacity of the top-five innovative countries. Technological capacity is measured as annual patent counts weighted by average quality. The authors' analysis covering 2001 to 2009 shows that the US is leading in overall technological capacity, followed by Japan, Germany, and Korea, while China takes the last position.

Analyzing more recent patent data up to 2019, Breitinger et al. (2020) identify the top 10% patents in force for 58 forward-looking technology areas, which is measured by family size and forward citations. After attributing patents to countries according to inventor addresses, the findings demonstrate the dominant position of the US while also highlighting growing patenting activities in East Asia, notably China, in recent years. The US leads in 50 of the 58 technologies evaluated in the study. In contrast, European countries appear to be lagging behind, leading in only two technology areas of wind energy and functional foods. However, the results also highlight the inventiveness and dynamism of East Asia, which has surpassed the US in some areas and is closing the gap in others. China has gained considerable momentum in recent years and is advancing more rapidly than the US and Europe in almost all sectors. Additionally, countries outside of the three leading innovation regions find it challenging to obtain a significant role.

Using an alternative approach, Bergeaud and Verluise (2022) measure countries' global influence based on the number of patent applications, forward citations, and the radicalness inferred from patents' semantic content. Focusing on six frontier technologies from 1974 to 2019, the authors observe that the US maintains a relatively high position in all technologies when considering the quantity of applications, while Europe's significance is limited to fewer technologies. The steady growth of China's influence is also confirmed, while the proportion of Japanese patents drops to a lower level by 2019, indicating Japan's declining significance as an innovation hub (Criscuolo and Timmis 2018; Ito et al. 2019). Notably, Bergeaud and Verluise (2022) confirm that Chinese patents are of inferior quality compared with European, US, and Japanese counterparts. Nonetheless, this gap is narrowing over time. In general, the patenting activities in frontier technologies are increasingly polarized between the US and China as the main players.

Other studies investigate the bilateral influence between countries. Cerdeiro et al. (2021) analyze the impact of global knowledge flows on countries' economic performance from 2000 to 2013. For China and other countries, the primary sources of knowledge spillovers are the US and Japan, to a lesser extent. China's contribution to other countries is substantial and exceeds that of the traditional technological leaders in Europe. All countries, including the US, appear to have increasingly benefited from China's innovation drive. Han et al. (2023) examine the bilateral relationship between the US and China, developing measures for technology decoupling and dependence. The authors reveal a consistent rise in technological integration (as opposed to decoupling), with China's reliance on the US increasing in the first decade and subsequently reducing in the second decade of the millennium.

Related literature examines global influence through scientific publications. According to the Nature Index 2023, China has overtaken the US for the first time in the natural sciences, which include the physical sciences, chemistry, earth and environmental sciences, and biological sciences (Nature 2023). The metric considers each author's share of articles published in 82 scientific journals between 2015 and 2022. However, recent studies provide a more nuanced picture of China's scientific prowess. Qiu et al. (2022) demonstrate that the high impact of US-based research on Chinese scientific publications persists. Nonetheless, Chinese scientists working in China and abroad are now significant contributors to the global knowledge frontier; however, cross-border frictions to knowledge spillovers persist in both directions. For example, Qiu et al. (2022) show that even after controlling for the quality of Chinese research, articles by Chinese principle investigators receive 28% fewer citations from US researchers. Xie and Freeman (2021) find that Chinese researchers abroad can alleviate such frictions, determining that an article from a diaspora author is more likely to cite China-addressed papers than non-China-addressed articles without a diaspora author. Similarly, China-addressed articles are more likely to cite non-China-addressed papers with a diaspora author than non-China articles without a diaspora author.

Policymakers who are conscious of the need to strengthen technology sovereignty also implement measures to impede the free flow of ideas by restricting scientific collaborations. For example, the 2018 China Initiative in the US is a recent illustration of restrictions implemented on scientific cooperation between US and Chinese inventors. Aghion et al. (2023) find a negative effect of the initiative on average publication quality and US coauthors of Chinese researchers with prior US collaborations. Furthermore, this negative effect is stronger for Chinese researchers with higher research productivity and those who worked in US-dominated fields and/or topics prior to the policy shock. Interestingly, the policy impact goes beyond direct effects on the US and China, as European researchers have become more attractive as coauthors for Chinese researchers, whereas researchers in the US have suffered from policy intervention. Jia et al. (2023) find that the research conducted since the China Initiative coincides with a decline in the productivity of US scientists with previous collaborations with scientists in China relative to those with international collaborators outside of China, particularly when considering the impact of publications (proxied by citations).

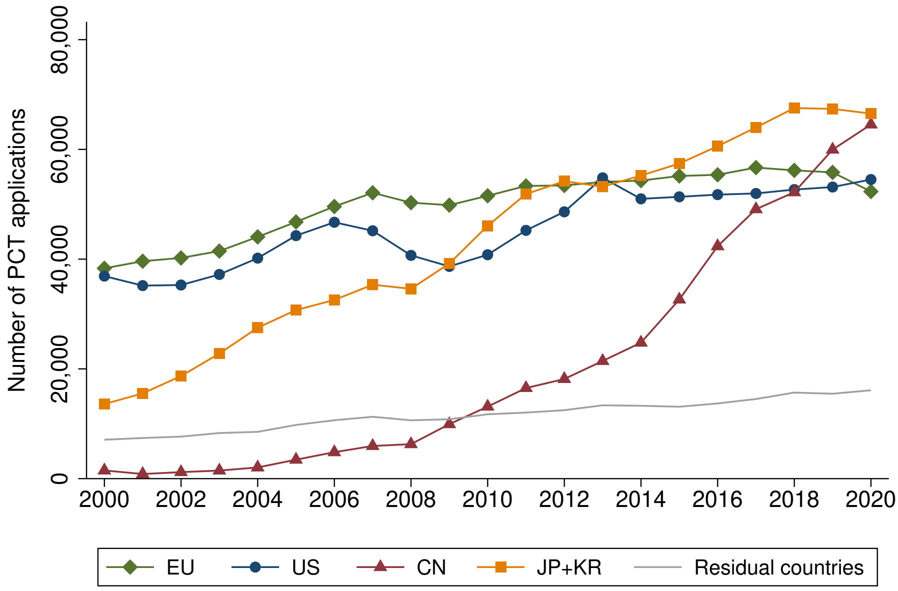
In summary, the literature underscores the enduring role of the US as a global knowledge source as well as China's ascent as a substantial knowledge contributor and user. However, the intensifying competition between these two major powers also has implications for research in other regions, in terms of innovation activities and the degree to which geographic areas bilaterally influence one another. In addition, more research is needed to investigate how these factors impact countries' technology sovereignty. In the next section, we describe how this study measures the global influence of geographic areas and their respective technology sovereignty.

# 3 Data and Measurement

## 3.1 The PCT system

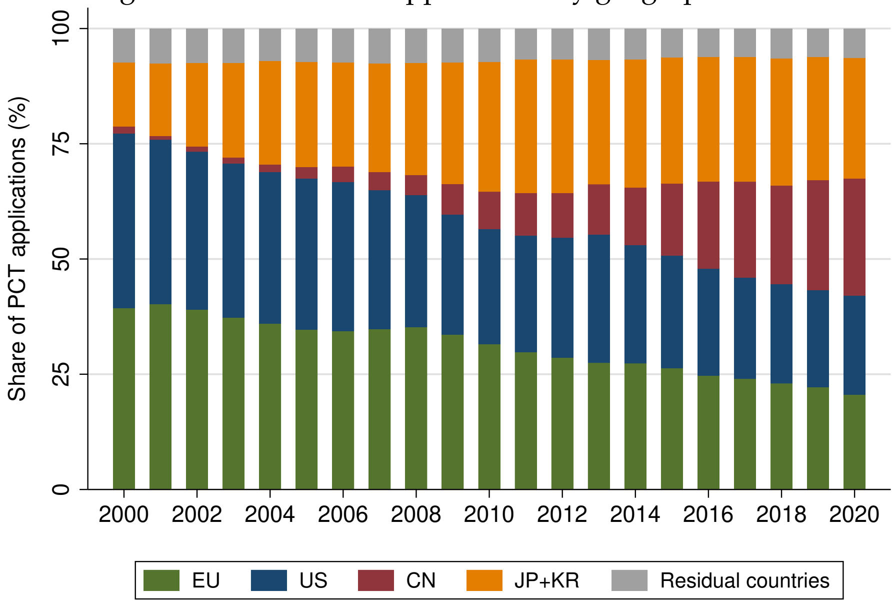
The PCT system, which is administered by United Nations' (UN) WIPO, allows applicants to simultaneously protect intellectual property in up to 157 countries. Figure 1 demonstrates that use of the PCT system has significantly expanded throughout the years, increasing from 97,414 filings in 2000 to 254,008 filings in 2020. Specifically, this growth is largely influenced by East Asian countries, particularly China, Japan, and Korea, in comparison to Western countries such as the US and European nations. China has been the number one ranked PCT applicant country since 2019, surpassing the US, Japan, Korea, and Germany. The shift in innovation activity from the West to the East is also reflected in Figure 2. In 2000, more than three-quarters of PCT applications originated from the US and Europe; however, Western dominance gradually decreased in the following two decades. By 2020, more than half of the global PCT applications originated from China, Japan, and Korea. In recent years, China and Korea have experienced considerable expansion while the US, Japan, and Germany have stagnated.

Figure 1: Number of PCT applications by geographic area




Under the PCT system, prior art searches are conducted within 30 months of filing the application during the international search phase. Designated national patent offices act as International Searching Authorities (ISAs), with all examiners following the same WIPO examination rules when preparing an ISR (WIPO 2022a). Confirming the influence of identical regulations, Michel and Bettels (2001) provide empirical evidence of highly similar citation rates for the USPTO, the EPO,

Figure 2: Share of PCT applications by geographic area




and the Japan Patent Office (JPO) when the patent offices prepare ISRs as ISAs. Regarding applicant citations, the rules of the PCT system state that the application should "indicate the background art which, as far as known to the applicant, can be regarded as useful for the understanding, searching and examination of the invention, and, preferably, cite the documents reflecting such art" (WIPO 2022b, Rule 5). Notably, the examiner ultimately decides which references are included in the ISR.

The selected references measure the technical and legal relationships among patents and are the appropriate measures of an invention's influence for our analysis. Restricting our analysis to citations from the ISR offers several important advantages. The PCT system applies common standards for searching prior art, which makes citations internationally comparable regardless of the nationality of the ISA conducting the search. The search guidelines explain in detail how citations should be selected by the examiners (WIPO 2022a, §15.63-§15.72). For example, examiners are encouraged to cite only the most relevant documents and to cite documents in the application's language, if several members of one patent family are available (WIPO 2022a, §15.69). As we aggregate citations at the family level, our measure is not influenced by which family member is actually cited.

International comparability is further enhanced because the search for prior art is highly concentrated among few ISAs. According to WIPO (2023, p. 75), the top-five ISAs were responsible for more than 90% of ISRs in 2022 (EPO, 37.8%; JPO, 21.1%; Korean Patent Office (KPO), 15.6%; USPTO, 9.7%; and SIPO, 9.5%). PCT applications move from the international to the national phase 30 months after priority. National patent offices conduct additional searches and examine the application prior to deciding to grant a patent. Citations in the national phase can differ from ISR citations as they follow national guidelines. To restrict the citations originating from only one data-generating process, we do not consider those generated during the national phase.

In international comparisons, it is essential to account for potential language barriers that deter patent examiners from identifying prior art from a specific country. Patent examiners typically begin their search for prior art with a keyword search in English. The PCT system provides an English translation of the main portions of PCT applications, including title, abstract, international search report, and any text related to figures for all PCT applications not published in English (WIPO 2022b, Rule 48.3 (c)). Abstracts have a key role in the search. According to Rule 8.3 (WIPO 2022b) "The abstract shall be so drafted that it can efficiently serve as a scanning tool for purposes of searching in the particular art, especially by assisting the scientist, engineer or researcher in formulating an opinion on whether there is a need for consulting the international application itself." Therefore, even if they are not originally published in English, PCT applications are easily identifiable as potentially relevant prior art. To account for additional language heterogeneity across patents, in the empirical analysis we also control for the date when the English full text patent document becomes available.

According to further guidelines of the PCT system, patent examiners conducting the international search have access to the minimum documentation standard, which specifies which prior art needs to be searchable for examiners. Regardless of the publication language used, PCT applications are part of this minimum standard. As such, all PCT applications are fully available during the search process.

### 3.2 Measurement

Following Boeing and Mueller (2016), we ensure comparability in the data-generating process of patent applications and citations by restricting our sample to PCT applications and citations generated in ISRs during the international phase. We only consider nonself-citations from abroad when measuring global influence because we are interested in the degree to which the inventions of one geographic area serve as the foundation for inventions in other areas. This approach also ensures independence from potential bias through domestic policy. The priority year indicates the year in which the first patent application for a given invention was filed, regardless of the chosen patent office. Country assignment of applications is based on the address of the first applicant, and we only consider citations from unique pairs of citing and cited patent families. Self-citations are determined based on DOCDB standard names from PATSTAT and EEE-PPAT application name harmonization (Magerman et al. 2006). We set the citation window to three years to ensure comparability and a high degree of timeliness.

We contribute to the literature by constructing empirical measures of technology sovereignty that are calculated based on PCT filings with priority years between 2000 and 2017 (the inclusion of more recent years would introduce truncation to our citation measure). Consistent with the focus of our analysis, we first assign all filings to the world's four leading innovation regions, i.e. (i) Europe,[7] (ii) the US, (iii) China, (iv) Japan and Korea,[8] plus a residual (the rest of the world). We also identify the main technology areas of each application based on its main International Patent Classification (there are 35 classes). We then quantify the number of citations a geographic area receives from another area and vice versa. Our empirical analysis focuses on three aspects.

First, we analyze the strength of the global influence at the patent level, where $i$ is the index for an individual invention as represented by a patent family and $K$ is the universe of PCT applications that can potentially cite (i.e., the PCT applications that have a priority date within the 3-year time period following the priority date of the individual invention of interest). The indicator function $\text{ISRcites}_{ik}$ equals one if application $i$ is cited by application $k$ within the defined time window and zero otherwise. This indicator function only considers nonself-citations received from applications from outside the own geographic area. Stated differently, all citations originating from any country within the own geographic area are excluded.

$$\text{ISRcitations}_{\,i} = \sum_{k=1}^{K} \text{ISRcites}_{\,ik} \tag{1}$$

Second, we explore the geographic direction of global influence and how it changes over time. This allows us to assess how important the influence of a focal geographic area is for other areas' inventions that contribute to the universe of PCT applications $K$. Hence, we observe the geographic area that the citing application $k$ is originating from and attribute the citation accordingly to the inventions of the focal geographic area. For example, a patent from the focal geographic area US is receiving a citation originating from a Chinese patent.

Third, to quantify bilateral influence, we sum all inventions in a geographic area in a given time period (2012–2017), excluding the time period subscript to simplify the notation. $\textit{Bilateral influence}_{LJ}$ denotes the bilateral influence that geographic area $L$ has with respect to area $J$. $L(J)$ represents the set of applications in area $L(J)$ in the given time period. In this way, we can determine whether bilateral

[7] We consider Europe as a whole as the European Union (EU) is increasingly governing geoeconomic and innovation-related topics of their member countries. In this study, Europe includes 30 countries: the EU-27 plus Norway, Switzerland, and the United Kingdom – which was an EU member country until January 2020.

[8] Combining Japan and Korea ensures that all four top innovation regions have similar global shares of PCT applications in recent years. Taiwan is excluded because it is not a member of the UN. Taiwanese applicants can only submit PCT applications indirectly through PCT member countries, which may involve additional administrative steps and costs compared to applicants from member countries.

dependence is reciprocal or skewed toward independence or dependence in the focal area.

$$\text{Bilateral influence}_{LJ} = \sum_{l=1}^{L} \text{ISR citations}_{l} - \sum_{j=1}^{J} \text{ISR citations}_{j} \tag{2}$$

### 3.3 Descriptive Statistics

We separate the time period 2000-2017 into three time spans of 2000–2005, 2006–2011, and 2012–2017. Table 1 presents the descriptive statistics for 1,252,148 PCT applications filed in the most recent period between 2012 and 2017. Among all applications, 10.1% received at least one and up to 68 ISR citations from other geographic areas. The mean and median values are 1.147 and 1, respectively, indicating a right-skewed distribution, which is commonly observed for patent citation data. Citations are from up to four other geographic areas, with mean and median values of 1.158 and 1, respectively, and from a maximum of 10 technology areas, with mean and median values of 1.096 and 1. The origin of PCT applications shows that Japan and Korea account for 27.5%, Europe accounts for 26.2%, the US accounts for 24.7%, China accounts for 15%, and residual countries account for 6.4%.

Table 1: Descriptive statistics

| | Mean | Median | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| ISR citations | 0.147 | 0 | 0.641 | 0 | 68 |
| ISR citations > 0 * | 1.471 | 1 | 1.463 | 1 | 68 |
| Citing geographic areas | 0.116 | 0 | 0.374 | 0 | 4 |
| Citing geographic areas > 0 # | 1.158 | 1 | 0.434 | 1 | 4 |
| Citing technology areas | 0.110 | 0 | 0.347 | 0 | 10 |
| Citing technology areas > 0 # | 1.096 | 1 | 0.344 | 1 | 10 |
| Europe (0/1) | 0.262 | 0 | | 0 | 1 |
| US (0/1) | 0.247 | 0 | | 0 | 1 |
| China (0/1) | 0.150 | 0 | | 0 | 1 |
| Japan and Korea (0/1) | 0.275 | 0 | | 0 | 1 |
| Residual countries (0/1) | 0.064 | 0 | | 0 | 1 |

Note: PCT applications between 2012 and 2017 are observed. The number of observations is $1,252,148$. #125,956 PCT applications receive > 0 citations.

Table 2 presents an overview of patent statistics by geographic area and also by three time spans of 2000–2005, 2006–2011, and 2012–2017. When observing the entire time period between 2000 and 2017, Europe contributed 31.1% of global PCT applications, closely followed by the US (30.0%) and Japan and Korea (25.0%), while China's overall contribution is more marginal (9.0%). This emphasizes the traditional importance of European and US invention. However, contrasting total patent applications from 2000 to 2005 with those from 2012 to 2017 reveals that China's contribution has increased by a remarkable 1,693.5%, while Japan and Korea only experienced an increase of 167.5%. In comparison, the US and Europe increased by only 35.1% and 31.3%, respectively. Notably, the strong rise in East Asia's patent quantity has resulted in a decline in average patent quality. When considering ISR citations received, the US has the highest ratio overall, followed by Europe, Japan and Korea, with China coming last. Peculiarly, average citations for China, Japan and Korea have reduced by about a quarter or more, while those of Europe and the US have remained remarkably stable. A similar pattern is observed for the average number of citing geographic areas and the average number of citing technology fields.

Table 2: Invention characteristics by geographic area

| | Europe | US | China | Japan and Korea | Residual countries | Total |
|---|---|---|---|---|---|---|
| PCT applications (count) | | | | | | |
| 2000-2005 | 250,496 | 229,051 | 10,506 | 128,860 | 48,784 | 667,697 |
| 2006-2011 | 306,716 | 257,312 | 56,619 | 239,651 | 67,140 | 927,438 |
| 2012-2017 | 329,038 | 309,537 | 188,480 | 344,648 | 80,445 | 1,252,148 |
| 2000-2017 | 886,250 | 795,900 | 255,605 | 713,159 | 196,369 | 2,847,283 |
| ISR citations (mean) | | | | | | |
| 2000-2005 | 0.133 | 0.237 | 0.114 | 0.134 | 0.268 | 0.179 |
| 2006-2011 | 0.120 | 0.218 | 0.103 | 0.111 | 0.237 | 0.152 |
| 2012-2017 | 0.128 | 0.242 | 0.084 | 0.101 | 0.215 | 0.147 |
| 2000-2017 | 0.127 | 0.233 | 0.089 | 0.110 | 0.236 | 0.156 |
| Citing geographic areas (mean) | | | | | | |
| 2000-2005 | 0.109 | 0.188 | 0.099 | 0.112 | 0.209 | 0.144 |
| 2006-2011 | 0.099 | 0.173 | 0.085 | 0.094 | 0.187 | 0.124 |
| 2012-2017 | 0.104 | 0.184 | 0.067 | 0.081 | 0.169 | 0.116 |
| 2000-2017 | 0.104 | 0.182 | 0.072 | 0.091 | 0.185 | 0.125 |
| Citing technology areas (mean) | | | | | | |
| 2000-2005 | 0.109 | 0.188 | 0.094 | 0.110 | 0.206 | 0.143 |
| 2006-2011 | 0.097 | 0.167 | 0.079 | 0.909 | 0.182 | 0.120 |
| 2012-2017 | 0.100 | 0.173 | 0.062 | 0.076 | 0.162 | 0.110 |
| 2000-2017 | 0.102 | 0.176 | 0.067 | 0.087 | 0.180 | 0.121 |

Note: The absolute number of PCT applications and mean values of citations are displayed. Citations only consider ISR citations received from other geographic areas.

## 4 Empirical Results

In this section, we first analyze the strength of global influence at the patent level for each geographic area and provide a rigorous validation of our measure. Second, we examine the geographic direction of global influence and how it changes over time. Third, to calculate bilateral influence, we consider all inventions from two geographic areas and calculate their respective mutual influence. We also calculate the average bilateral influence for each geographic area relative to all others and again observe changes over time.

### 4.1 Strength of global influence

Let $y_{it}$ represent patent $i$ filed in year $t$. For each patent, the main outcome is the number of ISR citations received from other geographic areas, as specified in Eq. (1). Variations in the outcome are assumed to depend on the geographic area ($k$) which the cited patent is originating from (e.g. the US, China, Japan and Korea, and residual countries), with Europe functioning as the reference category. Additional variables that capture patent-specific heterogeneity are summarized in $X_{it}$. Unobserved time and technology-specific factors are controlled for through year ($\varphi_t$), technology area fixed effects ($\varphi_a$), and year-technology area ($\varphi_{ta}$) fixed effects. $\varepsilon_{it}$ is an i.i.d. error term with a mean of 0 and variance of $\sigma^2_\epsilon$.

$$y_{it} = \alpha_0 + \gamma \sum_{k=1}^{K} \text{geographic area}_k + X_{it}\beta + \varphi_t + \varphi_a + \varphi_{ta} + \varepsilon_{it} \tag{3}$$

The main parameter of interest in Eq. (3) is $\gamma$, which measures the average effect of a patent's geographic origin on outcome $y_{it}$ (the number of ISR citations received from other areas over a three-year period). In this setting, a significant $\gamma$ would reject the null hypothesis of no correlation of patents' geographic origin on the extent of influence of the focal patent to other geographic areas. To broaden our analysis of influence, we also investigate two additional margins for each cited patent. First, we consider the number of citing geographic areas to capture the spatial dimensions of influence. Second, we consider the number of citing technology areas to measure patents' general relevance across the full range of 35 technology areas.

Table 3 presents our main regression results. We start by estimating Eq. (3) with the number of ISR citations as the outcome, considering the three time periods 2000–2005, 2006–2011, and 2012–2017 in columns, (1), (2), and (3), respectively. In comparison to the reference category Europe, patents originating from the US receive significantly more ISR citations. In contrast, patents of Chinese origin are associated with fewer citations. The results for both countries remain relatively persistent over the three time periods and become a bit more pronounced over time. In contrast, patents originating from Japan and Korea initially start off slightly stronger in comparison to Europe, but weaken significantly over time.[9] The coefficient of 0.094 for the US for the most recent time period (2012–2017) in column (3) indicates a level of influence that is 63.9% higher than the mean of the dependent variable, which corresponds to 0.147 citations. In contrast, for China we calculate a level of influence that is 66.0% lower than the mean. The corresponding value for Japan and Korea is -19.0%. Thus, the average strength of global influence varies widely between geographic areas. In column (4)–(7), we focus on the most recent time period and change the outcome to the number of citing geographic and technology areas. The results reveal a similar pattern as that of the number of ISR citations. Notably, the results remain qualitatively robust to the inclusion of the number of ISR citations as an additional control variable. This finding demonstrates that over and above receiving more ISR citations, patents from the US also have a stronger influence across geographic and technology areas. Overall, these results underscore that US inventions have a distinctive global influence through multiple channels. The opposite is shown for China, and to a lesser extent, Japan and Korea.

Table 3: Strength of global influence

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Time period | 2000-2005 | 2006-2011 | 2012-2017 | 2012-2017 | 2012-2017 | 2012-2017 | 2012-2017 |
| Dependent variable | ISR citations | ISR citations | ISR citations | Citing geo. areas | Citing geo. areas | Citing tec. areas | Citing tec. areas |
| US (0/1) | 0.089*** | 0.087*** | 0.094*** | 0.067*** | 0.023*** | 0.061*** | 0.023*** |
| | (0.002) | (0.002) | (0.002) | (0.001) | (0.001) | (0.001) | (0.001) |
| China (0/1) | −0.067*** | −0.103*** | −0.097*** | −0.068*** | −0.023*** | −0.061*** | −0.022*** |
| | (0.005) | (0.003) | (0.002) | (0.001) | (0.001) | (0.001) | (0.001) |
| Japan and Korea (0/1) | 0.003* | −0.014*** | −0.028*** | −0.024*** | −0.010*** | −0.025*** | −0.013*** |
| | (0.002) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Residual countries (0/1) | 0.131*** | 0.113*** | 0.084*** | 0.063*** | 0.023*** | 0.059*** | 0.025*** |
| | (0.003) | (0.003) | (0.003) | (0.002) | (0.001) | (0.002) | (0.001) |
| ISR citations | | | | | 0.468*** | | 0.406*** |
| | | | | | (0.011) | | (0.010) |
| Year FE | Y | Y | Y | Y | Y | Y | Y |
| Technology area FE | Y | Y | Y | Y | Y | Y | Y |
| Year-technology area FE | Y | Y | Y | Y | Y | Y | Y |
| Observations | 667,697 | 927,438 | 1,252,148 | 1,252,148 | 1,252,148 | 1,252,148 | 1,252,148 |
| R-squared | 0.034 | 0.028 | 0.029 | 0.037 | 0.659 | 0.031 | 0.575 |

Note: OLS regressions with robust standard errors in parentheses. ***p <0.01, **p<0.05, *p<0.1. The reference category is "Europe (0/1)".

We aim to estimate parameter $\gamma$ (the relationship between a patent's geographic origin and its global influence), which is measured by the number of ISR citations

[9] Because residual countries collectively account for only 6.9% of global PCT applications, we omit them from the discussion.

received from other geographic areas; however, bias may be introduced by omitted variables that confound origin and influence. To assess the robustness of our results, we compare our main results in column (1) of Table 4 which is identical to column (3) in Table 3, with results obtained after augmenting Eq. (3) with potential confounders. As a first step we control for the number of claims. While the average number of claims per patent may vary across countries; for instance, Japan is known to traditionally have fewer claims per patent (Goto and Motohashi 2007), the number of claims—and thus the inventive content of the patent—may positively influence the number of citations received. While a positive and significant relationship between claims and citations is confirmed in column (2), the magnitude of $\gamma$ drops significantly for Japan and Korea, confirming a lower average number of claims. Importantly, the baseline results remain robust. Second, we control for patenting by universities because the average number of citations received by science-oriented patents may be lower, introducing a negative bias for countries with more patents coming from universities. Indeed, column (3) shows a negative correlation between patent applications by universities and the number of ISR citations received; however, parameter $\gamma$ remains virtually unchanged across countries.

Table 4: Robustness tests (2012-2017)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Comparison | Claims | Universities | Authority | English | All |
| Dependent variable | ISR citations | ISR citations | ISR citations | ISR citations | ISR citations | ISR citations |
| US (0/1) | 0.094*** | 0.072*** | 0.095*** | 0.070*** | 0.079*** | 0.047*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| China (0/1) | −0.097*** | −0.073*** | −0.096*** | −0.044*** | −0.068*** | −0.016*** |
| | (0.002) | (0.002) | (0.002) | (0.001) | (0.002) | (0.002) |
| Japan and Korea (0/1) | −0.028*** | −0.004*** | −0.028*** | −0.033*** | −0.011*** | −0.006*** |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Residual countries (0/1) | 0.084*** | 0.097*** | 0.085*** | 0.082*** | 0.078*** | 0.085*** |
| | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Number of claims (log) | | 0.107*** | | | | 0.086*** |
| | | (0.002) | | | | (0.002) |
| University applicant (0/1) | | | −0.024*** | | | −0.006*** |
| | | | (0.002) | | | (0.002) |
| Chinese receiving office (0/1) | | | | 1.850*** | | 1.834*** |
| | | | | (0.014) | | (0.014) |
| English full text (0/1) | | | | | 0.097*** | 0.051*** |
| | | | | | (0.001) | (0.001) |
| Year FE | Y | Y | Y | Y | Y | Y |
| Technology area FE | Y | Y | Y | Y | Y | Y |
| Year-technology area FE | Y | Y | Y | Y | Y | Y |
| Observations | 1,252,148 | 1,252,148 | 1,252,148 | 1,252,148 | 1,252,148 | 1,252,148 |
| R-squared | 0.029 | 0.037 | 0.029 | 0.215 | 0.032 | 0.220 |

Note: OLS regressions with robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. The reference category is "Europe (0/1)". In model (2) we include a dummy variable for missing claims information.

Next, in column (4) we control for ISR citations generated at the Chinese Receiving Office, which recently has become the largest ISA in terms of examined PCT patent applications (WIPO 2023). China introduced national subsidies for patenting through PCT in 2009 (subnational support was already provided).[10] Cost reductions from subsidies disproportionately incentivize the excess production of patents of marginal value and the additional citations generated by such patents may inflate the original quality measure (see the discussion in Section 2.2). By construction, our measure prohibits patents receiving citations from their country of origin, but non-Chinese patents could still receive Chinese citations. Our results remain robust after including a dummy variable to control for citations of Chinese origin. In column (5), we address the concern that variation in the availability of a patent's full text in English confounds the cited patent's origin and the number of ISR citations received by including a dummy variable that takes the value of 1 once the full text is available in English, which could occur at the time of application or later. Unsurprisingly, the availability of full text in English is associated with more citations received; however, our main results remain robust. Finally, in column (6) we include the full vector of control variables and once again obtain robust results.

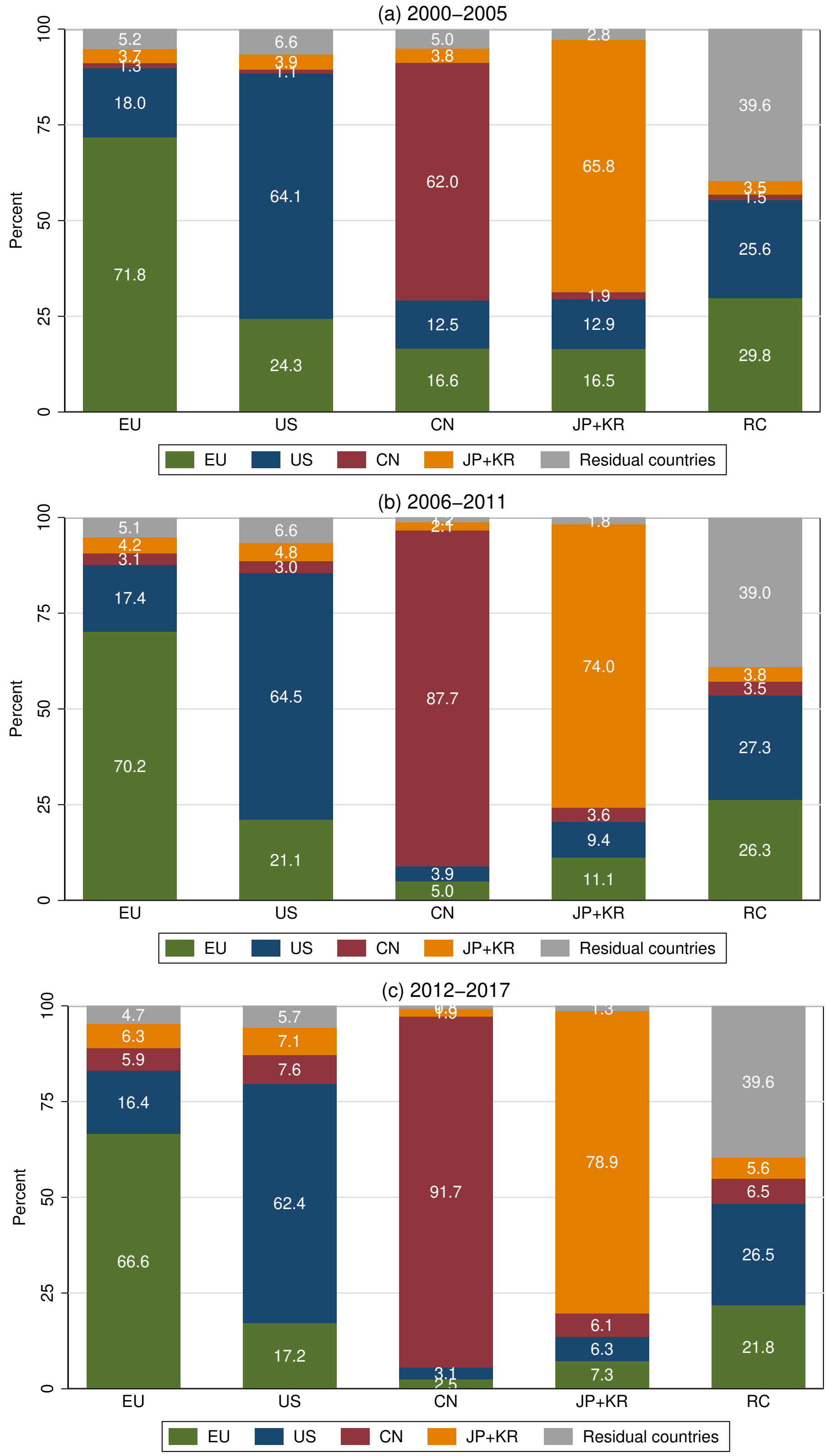
### 4.2 Geographic direction of global influence

We proceed with our analysis by considering the geographic direction of global influence, which allows us to assess the significance of the influence of a focal geographic area for other respective areas. To analyze the global influence of inventions relative to their domestic relevance, in this section we relax our strict selection criteria and also include domestic ISR citations. Although such citations may be inflated by domestic policies, which amounts to an upward bias in China's case (Boeing and Mueller 2019), this comparison is yet indicative of the level of technological self-reliance in a given geographic area. To analyze changes over time, we examine the periods 2000–2005, 2006–2011, and 2012–2017 in Figure 3. For the early time period, Panel (a) shows PCT patents originating in Europe receive 72% of ISR citations from within the immediate geographic area. European patents receive 18% of citations from the US, 1% from China, 4% from Japan and Korea, and 5% from residual countries. The economic implication is that European inventions are predominantly important for subsequent inventions in Europe. Despite a notable European influence on inventions in the US, the influence on other countries in the earlier years is more marginal.

Several insights stand out. Building on self-generated inventions is critical, as

[10] In 2009 China's Ministry of Finance introduced subsidies for PCT patenting. Applications in up to five countries are subsidized with a maximum of 100,000 RMB each (ca. 14,600 USD at an exchange rate of 31.12.2009) but more support is possible for projects involving significant innovation (Boeing and Mueller 2019).

Figure 3: Geographic direction of global influence




Note: The figure shows the geographic distribution of the origin of ISR citations received by the respective geographic area.

demonstrated by the fact that between 62% and up to 92% of the ISR citations come from the same geographic area. A notable degree of integration also occurs between Europe and the US, with 16% to 24% of ISR citations coming from other areas, highlighting the potential of international cooperation. In addition, the share of ISR citations from other geographic areas to Europe and the US grew from 10% and 12%, respectively, in the early time period to 17% and 21% in the late time period. The rationale for this increase is that the number of PCT applications strongly increased in East Asia; thus, these geographic areas produced more inventions that refer to Western inventions. Overall, this illustrates that inventions from Western countries continue to exert broad global influence.

In contrast, the proportion of domestic ISR citations received in China as well as Japan and Korea increased to 92% and 79%, respectively. Although China's domestic ISR citations are biased upward by subsidy policy, our analysis still suggests an increasing degree of technological self-sufficiency combined with a declining global influence of Chinese innovation in relative terms. In recent years, only 21% of ISR citations in Japan and Korea and 8% in China came from abroad, compared to 38% in the US and 32% in Europe. These patterns highlight a strong domestic orientation of East Asia, with lesser influence on innovation developed elsewhere.

### 4.3 Bilateral influence

Technology sovereignty positions geographic areas heterogeneously in terms of technological influence and dependence. The desired balance between global integration (complementarity) and national self-sufficiency (substitution) determines domestic R&D needs. Considering bilateral influence, a country's dependence on foreign technology and the influence of its domestic R&D abroad depend on the nature of its domestic R&D. Therefore, given the technological relationships between any two geographic areas, domestic R&D has a crucial role in avoiding one-sided dependence that can erode the technology sovereignty of a more dependent nation. To that end, pursuing complementarity is an efficient strategy, but only if there is sufficient reciprocal bilateral dependence. In this section, we present measures for bilateral influence and dependence.

Considering the time period 2012–2017, Table 5 presents the bilateral influence of the focal geographic area indicated in the top row in relation to the areas noted in the column below. This measure considers both the influence and quantity of inventions. A value of 0 indicates complete reciprocity between the two areas, while an upper (lower) bound of 100 (-100) implies full independence (dependence) of the focal area in relation to the other area. For this measure, we quantify the number of ISR citations that the patents of one geographic area obtain in one year from the other bilateral area. If the focal geographic area obtains more ISR citations than it gives to this area, then the focal area is deemed more independent.[11] For instance, a value of -22 suggests that Europe depends more on the US than the US does on Europe, whereas a value of 27 indicates that Europe depends less on China than China does on Europe. Europe's (weighted) average bilateral influence value of -8 indicates modest reliance on foreign innovation overall, placing the continent at a disadvantage in its global technology sovereignty, except in relation to China.

Table 5: Bilateral influence (2012-2017)

| | Europe | US | China | Japan and Korea | Residual countries |
|---|---|---|---|---|---|
| Europe | | 22 | -27 | 14 | 6 |
| US | -22 | | -48 | -20 | -14 |
| China | 27 | 48 | | 47 | 18 |
| Japan and Korea | -14 | 20 | -47 | | -4 |
| Residual countries | -6 | 14 | -18 | 4 | |
| Avg. weighted bilateral influence # | -8 | 26 | -39 | 8 | 0 |

Note: Columns show the bilateral influence of the focal geographic area with respect to the other areas: 0 refers to reciprocity between two areas, 100 refers to full independence, and -100 refers to full dependence. # The average bilateral influence is weighted by the shares in the number of patents of the respective geographic area.

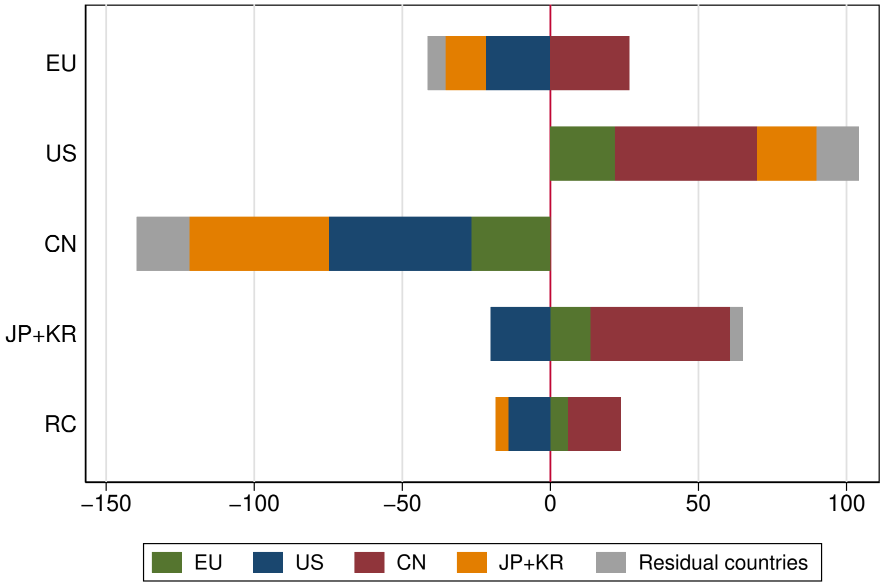
Notably, the US consistently shows higher levels of independence in relation to all other geographic areas, as demonstrated by its bilateral influence value of 26 on average. In addition, the US exhibits the strongest position in relation to China (48). Conversely, China has the weakest overall position, with an average bilateral influence of -39. Additionally, China exhibits significant dependence on the US and is similarly dependent on Japan and Korea with a value of -47, while its dependence on Europe is relatively lower at -27. Finally, Japan and Korea exhibit greater independence in relation to almost all other countries, as evidenced by a value of 8 in terms of the average bilateral influence. Except for the US, with -20, Japan and Korea demonstrate positive values, such as 14 vis-à-vis Europe.

For a more comprehensive global perspective, in Figure 4 we illustrate the stacked bilateral influence for each geographic area. Because we are quantifying the bilateral influence over all four partner areas, upper and lower bounds extend from 100 and -100 to 400 and -400, respectively. While values for bilateral influence are presented in Table 5, Figure 4 allows for a more detailed and comprehensive representation of global properties, both indicating variation within and across geographic areas. Notably, the US is the only country with consistent bilateral independence, amounting to 104, while China is the only country with consistent dependence, amounting to -140. Both Europe and Japan and Korea have rather mixed accounts of stacked bilateral influence, with more moderate respective up-

[11] The measurement of bilateral influence is described in more detail in the Appendix, where the full details of our measure calculation are presented in Table A1.

per and lower values of 27 and -42 as well as 65 and -20.

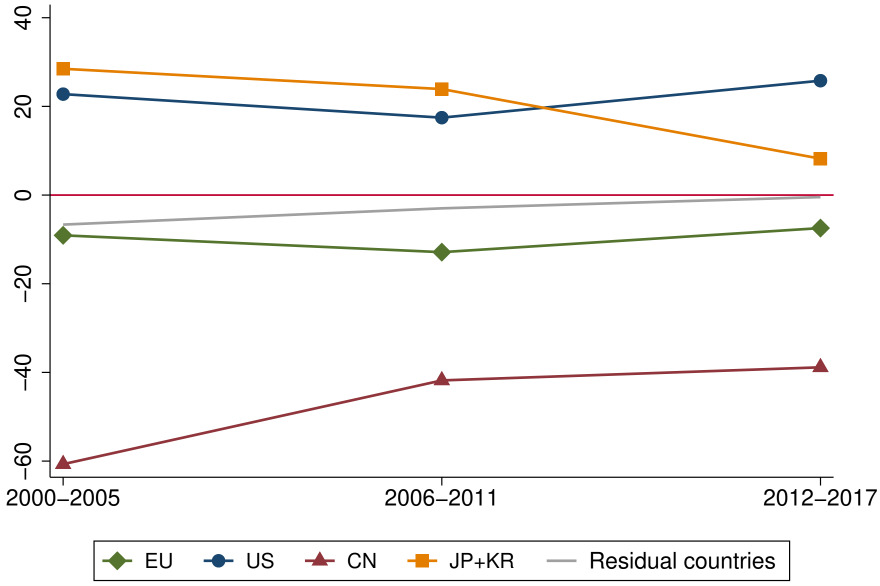
Figure 4: Stacked bilateral influence (2012-2017)




Notes: For each focal geographic area the bar shows the bilateral influence of that area with respect to the other four areas. 0 refers to reciprocity between the focal area and all other areas, 400 refers to full independence, and -400 refers to full dependence.

Figure 5 displays the average bilateral influence for each geographic area relative to the aggregate of all other areas. Again, a value of 0 indicates reciprocity, 100 indicates full independence, and -100 indicates full dependence. Notably, Europe and the US remain relatively stable and exhibit similar trends over time. Specifically, the US fluctuates between 17.6 and 25.8, whereas Europe ranges from -12.9 to -7.5. The position of Japan and Korea has weakened over time, declining from 28.5 to 8.2. In contrast, a continuous increase in the bilateral influence of China from -60.7 to -38.9 is shown, which still positions China below other areas. In summary, the traditional innovation areas of Europe and the US have remained stable over the last two decades, considering both the influence and quantity of inventions; however, the rise of China and the decline of Japan and Korea are also evident over time. The decrease in the average influence of China's PCT patent filings is outweighed by increased quantity. In contrast, Japan and Korea are experiencing a decline in influence without a sufficiently robust rise in quantity, leading to a decrease in overall bilateral influence over the past two decades.

Figure 5: Average weighted bilateral influence over time (2000-2017)




Notes: For each focal geographic area the average bilateral influence with regard to all other areas is displayed. 0 refers to reciprocity, 100 refers to full independence, and -100 refers to full dependence.

### 4.4 Key enabling technologies

Key enabling technologies (KETs) are crucial for the development and continuation of technology sovereignty. Such technologies have versatile applications across numerous technology fields and economic sectors, possess strong, nonsubstitutable complementarity with multiple other technologies, and have a considerable potential for performance enhancement. Therefore, we conduct an additional analysis focusing on KETs from 2012 to 2017. Empirically, KETs are classified referencing the criteria outlined in Van de Velde et al. (2013), encompassing nanotechnology, photonics, industrial biotechnology, advanced materials, micro and nanoelectronics, and advanced manufacturing technologies. Besides the economic importance, the focus on KETs also offers a methodological advantage. While countries' actual technology sovereignty is partly determined by their endogenous selection of technologies, KETs are a rather exogenous selection of technologies that are similarly relevant for all geographic areas.

From 2012 to 2017, 17.8% of PCT patent applications were classified as KETs. Notable heterogeneity is evident in the share of KETs across geographic areas. In decreasing order, we find values of 21.2% in Japan and Korea, 19.5% in the US, 16.9% in Europe, and only 10.9% in China. Considering the international influence of KETs based on average ISR citations received (compared with Table 2), the US leads with a mean value of 0.257 for KETs, in comparison to a mean value of 0.242 for all PCT applications. The corresponding values are 0.171 and 0.128 for Europe, 0.073 and 0.101 for Japan and Korea, and 0.099 and 0.084 for China. Notably, Europe shows the highest positive difference (4.30%) whereas a negative difference is found only for Japan and Korea (-2.80%), suggesting disadvantages in these technologies. Regression analysis corroborates this finding. When we replicate our benchmark model (Table 3, column (3)) with a restriction to KETs and compare it to the original results, the more negative coefficient of Japan and Korea stands out. The coefficient is -0.082 for KETs, while it is only -0.028 for all technologies; thus, compared with the reference category of Europe, Japan and Korea are at a stronger disadvantage. For China, we obtain a coefficient for KETs of -0.069 compared to -0.097 for all technologies, while in the US, the respective coefficients are 0.065 and 0.094. The smaller positive coefficient for KETs in the US confirms Europe's advantage in KETs.

The direction of global influence reveals only minimal differences for KETs compared to all technologies (compare Figure 3). However, Japan and Korea have a substantially increased share of their own ISR citations, rising from 79% to 87%. This suggests that KET inventions have a lesser influence on other geographic areas. This is despite the fact that Japan and Korea have the highest absolute number of KET patent applications in the most recent time period, with 25,214, in comparison to 23,663 in the US, 16,234 in Europe, and 11,186 in China. Finally, replicating the results for bilateral influence restricted to KETs (compare Table 5), reveals the following notable results. Europe improves its weighted average bilateral influence from -8 to 1, while Japan and Korea drop from 8 to -1. Japan and Korea have a comparatively lower influence, in particular toward Europe (-2 in KETs vs. 14 for all patents) and the US (-31 in KETs vs. -20 for all patents), and in relation to China as well (39 in KETs vs. 47 for all patents). The decline in Japan and Korea's bilateral influence is attributable to an extremely low rate of foreign ISR citations, which cannot be compensated by the strong activity in terms of the absolute number of PCT applications.

## 5 Discussion and Policy Implications

In this section, we first discuss our main results and then outline policy implications. Across all results, it is evident that the US has maintained its influential position as the world's technological superpower. The US has the strongest global influence and surpasses all other countries in respective bilateral relationships, establishing superior technology sovereignty. However, this conclusion is far from obvious. Since 2019, China has overtaken the US, Japan, Korea, and Germany as the number one country in terms of PCT patent applications. Additionally, there is anecdotal evidence that China has been making substantial progress in certain future-oriented technology areas such as batteries (Breitinger et al. 2020). Nonetheless, our analysis suggests that China's focus on quantitative patent targets combined with industrial and innovation policies and occasional moonshot projects has not yet amounted to inventions with an overwhelming global influence. In contrast, our findings reveal China's continuous dependence on all other geographic areas, which is evident across all technologies and future-oriented KETs. Despite improving its average weighted bilateral influence throughout the first decade of the millennium, China's recent growth trend is similar to the US and Europe, albeit its level being significantly lower. Hence, our results do not suggest that China is about to overtake the US as the world's technological superpower.

Another important insight is the strong mutual relationship between the US and Europe with respect to the direction of global influence. In comparison to this high degree of integration in the West, for East Asia, we find a growing internal focus of geographic areas over time. Notably, this is true for China, which is explicitly seeking to reduce foreign dependence as well as Japan and Korea. A remarkable finding is that Japan and Korea are actually becoming weaker in terms of average bilateral influence over time, representing the only area with a downward trend. In contrast, the US, Europe, and China have improved their positions. The cases of China (for all PCT applications) and Japan and Korea (for KETs PCT applications) also demonstrate that leadership in quantity does not necessarily equate to a higher technological influence. For example, while Europe files a relatively lower quantity of PCT applications in KETs, the respective influence is actually stronger than in total technologies.

Several implications emerge from our findings for policymakers to consider. Despite ongoing integration between the US and Europe in the midst of a changing global geoeconomic landscape, the US and Europe differ markedly in their respective global positions. The US has achieved outstanding technology sovereignty, whereas Europe is dependent on all geographic areas except China. Therefore, it is crucial for European policymakers to address this dependency. An essential aspect of a related policy approach should focus on promoting KETs, as Europe has already obtained relative advantages in these future-oriented technologies. European policymakers view the US, Japan, and Korea as dependable partners, limiting the need for immediate bilateral interventions; thus, Europe should strive for more balanced, long-term bilateral partnerships with these countries, while also avoiding dependence on Chinese innovations in the future.

Policymakers in Japan and Korea face distinct challenges. This geographic area has a very high global bilateral influence and relies solely on the US, which it considers a reliable partner. Despite this, it has experienced a decline over time, albeit from a high level. Addressing the cause of this trend is imperative for policymakers. Japan and Korea have made important contributions to global innovation for several decades, and this area is also highly involved in future-oriented innovation related to KETs; however, this inventive activity has not yet been adequately translated into international influence. Innovation from Japan and Korea is cited less frequently abroad over time, not just from fewer geographic and technology areas, resulting in a reduction in its overall influence.

Finally, Chinese policymakers face a difficult circumstance. The geoeconomic climate is characterized by a systemic rivalry, which partially originates from China, and other countries' push for technology sovereignty can be seen as a response to this. Additionally, the US, Europe, and other geographic areas are also promoting de-risking in commodity trade and foreign direct investment. China is considered to be an unreliable partner by these countries based to concerns that Chinese policymakers may leverage economic and technological dependence during periods of conflict. The timing of these events poses a challenge for China, as it has made significant strides in terms of the quantity and influence of inventions, but remains more dependent on other geographic regions than the reverse.

Although maximal global integration seems not to be the order of the day, collaboration among like-minded and geoeconomically reliable partners still allows countries to benefit from their inclusion in the global innovation network. However, cooperation with less reliable countries should be embedded in a setting of at least reciprocal bilateral dependence, while actively reducing unilateral dependence but building up inventive capacity domestically or among reliable partners.

# 6 Conclusion

We analyze the technological influence and interdependence of the world's leading innovation regions to investigate their technology sovereignty, a concept at the crossroads of geoeconomics and innovation studies. This paper introduces a novel empirical approach that measures bidirectional knowledge flows using patent citations observed through the universe of PCT applications, and offers a first empirical assessment of technology sovereignty. The US maintains its status as the leading technological superpower, exerting strong global influence and outpacing all other geographic areas in bilateral relations, thus maintaining superior technology sovereignty. Despite persistent integration between the US and Europe in the midst of a changing global geoeconomic landscape, the US and Europe differ substantially in their respective global positions. Europe is dependent on all geographic areas except China. Although China has shown a strong rise in patent counts, our research reveals that it is dependent on all other geographic areas. This is the case for the total of all technologies as well as for future-oriented technologies separately. Notably, Japan and Korea have witnessed a decline in their average bilateral influence over time, despite previously holding a top position. As a result, they are the only geographic area to show a recent downward trend.

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## Appendix

Table A1 contains the figures that underly the calculation of the measure of bilateral influence as shown in Table 5. A value of 0 refers to reciprocity between two geographic areas, 100 to full independence, and -100 to full dependence. The measure of bilateral influence is calculated as the ratio of the total citations received by area L from area J minus the total citations received by area J from area L divided by the sum of the respective citations received.

To make the calculation concrete we explain the calculation of the value of bilateral influence of -22 that Europe (region L) has with respect to the US (region J) as reported in the first entry of the first column of Table 5. The value of -22 marks a slight dependence of Europe on the US. The value is calculated by taking the total citations that Europe received from the US, 20,791, and subtracting the total citations that the US received from Europe, 32,384. Both values are displayed in Table A1. This results in a difference of -11,593. This difference is divided by the sum of the respective citations received, 20,791 plus 32,384, which equals to 53,175. The ratio of the two terms, -11,593 divided by 53,175, equals to -22%, which is the final measure of the bilateral influence of Europe on the US.

When it comes to the bilateral influence of Europe with respect to China, the respective calculation is (7,788-4,505)/(7,788+4,505) = 27%. The value of 27 can be found in the second entry of the first column of Table 5.

Table A1: Number of ISR citations received (2012-2017)

| | Europe | US | China | Japan and Korea | Residual countries | Total |
|---|---|---|---|---|---|---|
| Europe | 80,422 | 32,384 | 4,505 | 11,024 | 6,039 | 134,374 |
| US | 20,791 | 118,094 | 5,823 | 10,653 | 7,703 | 163,064 |
| China | 7,788 | 16,603 | 138,655 | 11,511 | 1,952 | 176,509 |
| Japan and Korea | 8,389 | 16,024 | 4,141 | 128,685 | 1,754 | 158,993 |
| Residual countries | 5,353 | 10,249 | 1,363 | 1,910 | 10,610 | 29,485 |
| Total citations | 122,776 | 193,433 | 154,567 | 163,796 | 28,073 | 662,425 |
| Total citations (%) | 18.5 | 29.2 | 23.3 | 24.7 | 4.2 | 100.0 |
| Total patents | 329,038 | 309,537 | 188,480 | 344,648 | 80,445 | 1,252,148 |
| Total patents (%) | 26.3 | 24.7 | 15.1 | 27.5 | 6.4 | 100.0 |

Note: The table shows the number of ISR citations received by a geographic area, i.e. its global influence. E.g., the USA obtained 16,603 citations from China whereas China obtained 5,823 citations from the USA.

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