

Geopolitical Fragmentation and the Geography of 5G Innovation



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Abstract

This study examines how the U.S.–China technological rivalry reshapes inventive collaboration in core 5G infrastructure technologies. Using 106,117 priority patent applications filed by leading 5G patenting firms between 2010 and 2023, we construct patent-level measures of inventor collaboration and diversity across geopolitical blocs. To identify the effects of geopolitical fragmentation, we exploit differences in firms' pre-existing exposure to cross-bloc inventor integration and the changes in global cross-bloc co-invention over time.

Geopolitical fragmentation significantly reduces cross-bloc inventor integration. Firms with greater pre-existing exposure to cross-bloc knowledge recombination experience larger declines in collaboration as fragmentation intensifies. A one-standard-deviation increase in the fragmentation shock reduces the likelihood of collaboration between U.S. and Chinese inventors by 2.1 percentage points, or roughly one quarter relative to the sample mean. Fragmentation also reduces inventor diversity and the share of inventors from rival geopolitical blocs, with the most pervasive and statistically robust effects observed among Chinese companies.

Tiivistelmä

Geopoliittinen fragmentaatio ja 5G-innovaatioiden maantiede

Tarkastelemme, miten Yhdysvaltojen ja Kiinan välinen teknologinen kilpailu muokkaa innovaatioyhteistyötä 5G-teknologioissa. Analyysi perustuu johtavien 5G patentoijayritysten vuosina 2010–2023 jättämiin 106 117 patenttihakemukseen. Patenttiaiaineiston avulla muodostetaan mittarit geopoliittisten blokkien väliselle keksijäyhteistyölle ja keksijätiimien monimuotoisuudelle. Geopoliittisen fragmentaation vaikutuksia arvioidaan hyödyntämällä yritysten eroja niiden aiemmassa altistumisessa blokkirajat ylittävälle keksijäyhteistyölle sekä muutoksia globaalissa blokkirajat ylittävässä yhteiskeksimisessä.

Geopoliittinen fragmentaatio vähentää merkittävästi geopoliittisten blokkien välistä keksijäyhteistyötä. Vaikutukset ovat voimakkaimpia yrityksissä, joiden innovaatioverkostot olivat ennen geopoliittisten jännitteiden kärjistymistä vahvasti integroituneita blokkirajojen yli. Yhden keskihajonnan suuruinen kasvu fragmentaatio-osiosokissa pienentää yhdysvaltalaisien ja kiinalaisten keksijöiden välisen yhteistyön todennäköisyyttä 2,1 prosenttiyksiköllä, mikä vastaa noin neljänneksen laskua suhteessa yhteistyön keskimääräiseen tasoon. Geopoliittinen fragmentaatio vähentää myös keksijätiimien monimuotoisuutta ja geopoliittisesti vastakkaisista blokkeista tulevien keksijöiden osuutta. Vaikutukset ovat laaja-alaisimpia kiinalaisyrittäjissä.

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Keywords: Geopolitical fragmentation, Technological decoupling, 5G, Innovation networks, Cross-border collaboration, Inventor networks

Asiasanat: Geopoliittinen fragmentaatio, Teknologinen irtikytkentä, 5G, Innovaatioverkostot, Kansainvälinen yhteistyö, Keksijäverkostot

JEL: F23, O32, O33, L96, D85

1. Introduction

Recent geopolitical tensions between the United States and China have increasingly extended into strategically critical technologies, such as 5G. Export controls, sanctions, and other technology restrictions have been widely discussed as instruments for reshaping trade patterns, global value chains, and access to advanced technologies (Nocetti, 2022). However, much less is known about how such policies affect the organization of innovation itself. Because innovation often relies on the recombination of knowledge across firms, countries, and inventor teams, restrictions on cross-border interactions may have consequences that extend beyond production and trade. This paper examines whether and how rising geopolitical tensions reshape cross-border inventive collaboration in frontier 5G technologies.

We study this question in the context of fifth-generation mobile communication (5G) infrastructure technologies, a strategically important domain at the center of the U.S.–China technological rivalry. Beginning in 2018, escalating U.S.–China trade and technology tensions led to a series of export-control measures and entity-list sanctions targeting firms such as Huawei. At the same time, concerns regarding technological dependence and network security prompted the European Union to introduce the EU 5G Toolbox, a coordinated framework for managing security risks associated with high-risk vendors. Together, these developments have increased geopolitical frictions within the global 5G ecosystem and created a setting in which international collaboration may become more costly or politically constrained.

Geopolitical interventions can affect innovation through their impact on cross-border knowledge flows. Because innovation frequently relies on combining geographically dispersed expertise, restrictions on international interaction may alter both the incentives and opportunities for such recombination. This mechanism is consistent with the framework of Lind and Ramondo (2024), which highlights the joint roles of innovation and international knowledge diffusion in shaping technological development. Rather than simply reducing innovation, geopolitical fragmentation may therefore reshape the geography of inventive activity by redirecting collaboration toward domestic or politically aligned partners.

We focus on core 5G infrastructure technologies and analyze cross-border inventive collaborations among leading patenting firms in this domain. Innovation in 5G is highly concentrated among a limited number of globally active firms whose patenting activity defines the technological frontier. This concentration allows us to observe how politically induced changes in integration frictions translate into adjustments in inventor networks within tightly interconnected global innovation systems. By analyzing patent-level collaboration patterns, we assess whether geopolitical fragmentation alters the structure and composition of cross-border knowledge recombination in frontier technologies. Over the period 2010–2023, the top 50 patent owners accounted for approximately 70% of patents in core 5G technologies. Our empirical analysis focuses on 47 firms from this set (excluding three research institutes).

A large body of literature on innovation and international business shows that firms benefit from accessing geographically dispersed knowledge and that multinational enterprises organize such recombination through global R&D networks (Almeida & Kogut, 1999; Kogut & Zander, 1993; Mudambi, 2008). Related work highlights that the innovation returns to team diversity are non-linear because broader knowledge access must be balanced against coordination and integration costs (Reagans and Zuckerman, 2001; Seo et al., 2020). However, this literature has paid less attention to the possibility that cross-border inventive collaboration spans geopolitically contested and institutionally fragmented regimes. We contribute to the literature by introducing geopolitical fragmentation as a source of integration friction in global innovation networks and by showing how it reshapes cross-bloc knowledge recombination in a strategically important technology domain.

We find that rising geopolitical fragmentation reduces cross-bloc inventive collaboration in core 5G technologies. A one-standard-deviation increase in fragmentation lowers the probability of collaboration between U.S. and Chinese inventors by approximately 2.1 percentage points relative to a sample mean of roughly 8 percent, implying an economically meaningful decline in cross-bloc knowledge recombination. Fragmentation also reduces inventor bloc diversity and the participation of inventors from rival geopolitical blocs. These effects are broadest among Chinese firms, which exhibit the most consistent contractions in cross-bloc inventor integration. Overall, the results suggest that geopolitical fragmentation is reshaping frontier innovation networks by reducing cross-bloc collaboration and narrowing the geographic diversity of inventive teams.

The remainder of this paper is organized as follows. Section 2 develops a conceptual framework linking geopolitical fragmentation to cross-bloc inventive collaboration and the inventor-network structure. Section 3 describes the patent data and the construction of key measures. Section 4 outlines the empirical strategy and presents the main estimation results. Section 5 concludes and discusses the implications for innovation management and technology policy.

2. Conceptual framework

Innovation often depends on combining knowledge from various sources. Because knowledge spillovers are geographically localized (Jaffe, Trajtenberg, & Henderson, 1993; Audretsch & Feldman, 1996), firms benefit from accessing distinct and locally embedded knowledge pools across places (Almeida & Kogut, 1999). Therefore, a central rationale for multi-location R&D is to tap into heterogeneous scientific and technological capabilities located in different regions (Chung & Alcácer, 2002; Alcácer & Zhao, 2012). By allocating research activities across diverse locations, firms expand their opportunities for recombinant searches.

Multinational enterprises internalize the integration of dispersed knowledge through internal networks (Kogut & Zander, 1993; Gupta & Govindarajan, 2000; Mudambi, 2008). Internal

coordination mitigates transaction and communication costs, which would otherwise limit cross-border recombination. In this literature, however, geography primarily captures technological heterogeneity and spatially bounded spillovers, rather than politically induced barriers.

We extend this framework by introducing geopolitical fragmentation as an additional source of friction in knowledge recombination. We conceptualize geopolitical blocs as institutionally distinct knowledge regimes characterized by divergent regulatory environments, export control constraints, and security considerations. Cross-bloc collaboration, therefore, entails not only cognitive and organizational distance but also regulatory uncertainty and politically imposed restrictions. Therefore, geopolitical fragmentation increases the relative cost of cross-bloc knowledge recombination, shifting innovative activity toward within-bloc integration.

Firms' incentives to invest in research depend on the balance between internal appropriation and external spillovers. Arora et al. (2021) show that firms expand research when its outputs are used internally in downstream innovation, but reduce research when knowledge diffuses to rivals. In strategic technology domains characterized by geopolitical rivalry, cross-bloc collaboration entails not only coordination costs but also greater appropriation risks. As institutional divergence between geopolitical blocs increases, the protection and governance of intellectual assets across jurisdictions become less predictable. Cross-bloc R&D collaboration, therefore, exposes firms to a higher risk of unintended knowledge leakage and politically contingent restrictions on the use of innovation. Rather than eliminating international collaboration altogether, geopolitical fragmentation lowers the expected private returns from cross-bloc R&D collaboration.

Prior research documents non-linear returns to diversity in innovative activities. Geographic and technological heterogeneity enhance inventive performance up to the point at which coordination and integration costs dominate (Reagans and Zuckerman, 2001). Seo et al. (2020) make the tradeoff between knowledge diversity and integration costs explicit in the context of cross-border R&D teams, showing that geographic diversity exhibits an inverted-U relationship with innovation performance. Moderate diversity enhances access to location-specific knowledge assets, whereas excessive dispersion increases the costs of coordination and integration. Importantly, they demonstrated that team composition moderates this relationship by affecting the efficiency of knowledge integration. In geographically dispersed R&D teams, the technological distance between clusters likewise exhibits an inverted-U relationship with breakthrough innovation, moderated by the structure of intra- and inter-cluster ties (Vestal & Danneels, 2022).

Complementary work on recombinant search similarly shows that combining moderately distant knowledge components enhances innovation, whereas excessive distance increases the likelihood of coordination failure (Fleming & Sorenson, 2004; Uzzi et al., 2013). These findings imply that the benefits of heterogeneity depend on the balance between novel recombination and the integration costs.

We argue that in strategic industries such as 5G, geopolitical distance is a distinct dimension of heterogeneity. Unlike technological distance, geopolitical distance reflects institutional divergence and security-related constraints that amplify the costs of coordination and recombination. Whereas prior research emphasizes technological and team-level sources of integration friction, geopolitical fragmentation operates at the level of institutional regimes. As geopolitical fragmentation intensifies, the level of cross-border heterogeneity that maximizes innovation performance declines.

This perspective also connects to research on global innovation networks, which emphasizes how geographically dispersed actors coordinate knowledge creation across organizational and national boundaries (Ernst and Kim, 2002). However, in strategic technology domains, such networks are not purely organized around efficiency but are also shaped by geopolitical constraints. The value and feasibility of cross-bloc collaboration depend on geopolitical alignment. By examining patent-level collaboration patterns among leading firms in 5G, we provide evidence of how geopolitical fragmentation conditions the returns to cross-bloc recombinant search at the technological frontier.

These arguments yield three empirical implications for inventive activities in strategic technologies. First, firms whose innovation strategies rely more heavily on cross-bloc recombinant search should be more strongly affected by geopolitical fragmentation than firms with limited prior dependence on such linkages. Second, geopolitical fragmentation should reduce cross-bloc inventor collaboration, leading to fewer inventor bridges spanning the China–West divide. Third, geopolitical fragmentation should affect not only the formation of cross-bloc inventor links but also the broader geographic composition of inventive teams, resulting in lower inventor bloc diversity and a reduced presence of inventors from rival geopolitical blocs.

3. Data

Our empirical analysis focuses on leading patenting firms in core 5G technologies, identified using LexisNexis (2025) ranking of leading 5G patent holders and standards contributors based on ETSI data. Starting with the top 50 organizations in this ranking, we excluded three research institutes and retained 47 companies for the empirical analysis. Patent data were retrieved from the PatentInspiration database. We organize the data at the patent family level and retain one observation per family, corresponding to the earliest priority application filed between 2010 and 2023. This approach avoids double counting across jurisdictions and anchors each invention to its original date of filing.

Patents are identified based on the USPTO (2022) classification and categorized under CPC (Cooperative Patent Classification) subclasses H04W72, H04L5, H04L1, and H04B7, which cover essential 5G radio access, transmission, and network control functions. Restricting the sample to patents containing at least one of these CPC subclasses yields 106,117 unique

priority patent applications in the dataset. These patents represent approximately 70% of global filings in core 5G domains, reflecting a concentrated innovation landscape dominated by a small group of multinational corporations.

Each patent is assigned to the country of the firm's ultimate headquarters. Inventor locations are mapped into four geopolitical blocs: the United States, the European Union and the United Kingdom, China, and other Asian economies. Cross-bloc collaboration is defined as the presence of inventors from both Western economies (the U.S. or EU/UK) and China on the same patent. Alternative measures include the share of inventors from rival geopolitical blocs and inventor-country diversity within a patent, which capture the political composition and geographic diversity of inventor teams. Table 1 presents the descriptive statistics of the variables used in the empirical analysis.

Table 1. Descriptive statistics

	N	mean	sd	min	max
Conflict bridge	106117	0.091	0.288	0.000	1.000
US-CN bridge	106117	0.085	0.279	0.000	1.000
EU-CN bridge	106117	0.025	0.157	0.000	1.000
Conflict-bloc inventor share	106117	0.095	0.250	0.000	1.000
Inventor bloc diversity (1-HHI)	106019	0.087	0.177	0.000	0.800
CPC: H04W72	106117	0.606	0.489	0.000	1.000
CPC: H04L5	106117	0.487	0.500	0.000	1.000
CPC: H04L1	106117	0.308	0.462	0.000	1.000
CPC: H04B7	106117	0.200	0.400	0.000	1.000

Note: The US–CN and EU–CN bridge variables are binary indicators equal to one if a patent includes inventors located in both blocs. A conflict bridge is a binary indicator equal to one if a patent includes inventors located on both sides of the China–West geopolitical divide. Conflict-bloc inventor share measures the share of inventors in rival geopolitical blocs. Inventor bloc diversity is measured as 1-HHI across the inventor blocs. CPC indicators identify the main core 5G technology classes and are not mutually exclusive.

We begin by documenting changes in cross-bloc collaborations in the development of core 5G technologies among the largest patenting firms in the field. The analysis is restricted to patents classified in infrastructure-level 5G domains and distinguishes between two complementary dimensions of international integration: interorganizational collaboration, captured by cross-bloc co-application, and inventor-level integration, captured by the geographic distribution of the inventor teams.

Figure 1 reports the share of patents involving cross-bloc co-application between Chinese and Western firms among the top 50 patenting firms in core 5G technologies. Such collaborations are rare throughout the sample period and decline further after the mid-2010s. Even at its peak, less than two percent of patents involved applicants headquartered in different geopolitical blocs. The low incidence of cross-bloc co-application suggests that shared patent ownership plays a limited role in the international integration of inventive activity in core 5G technologies.

Figure 1. Cross-Bloc Co-Application in Core 5G Technologies

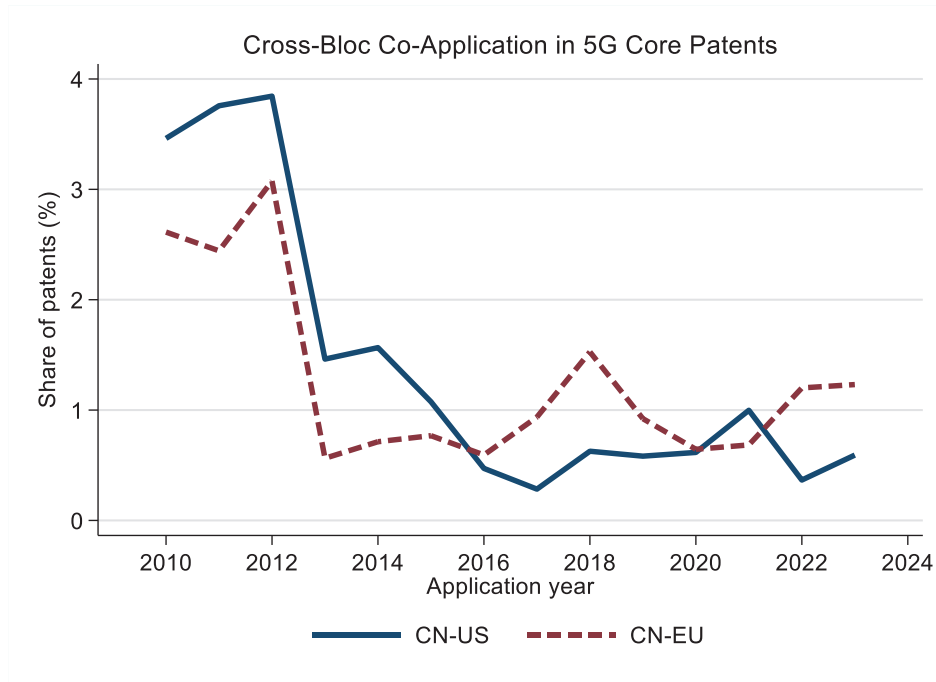
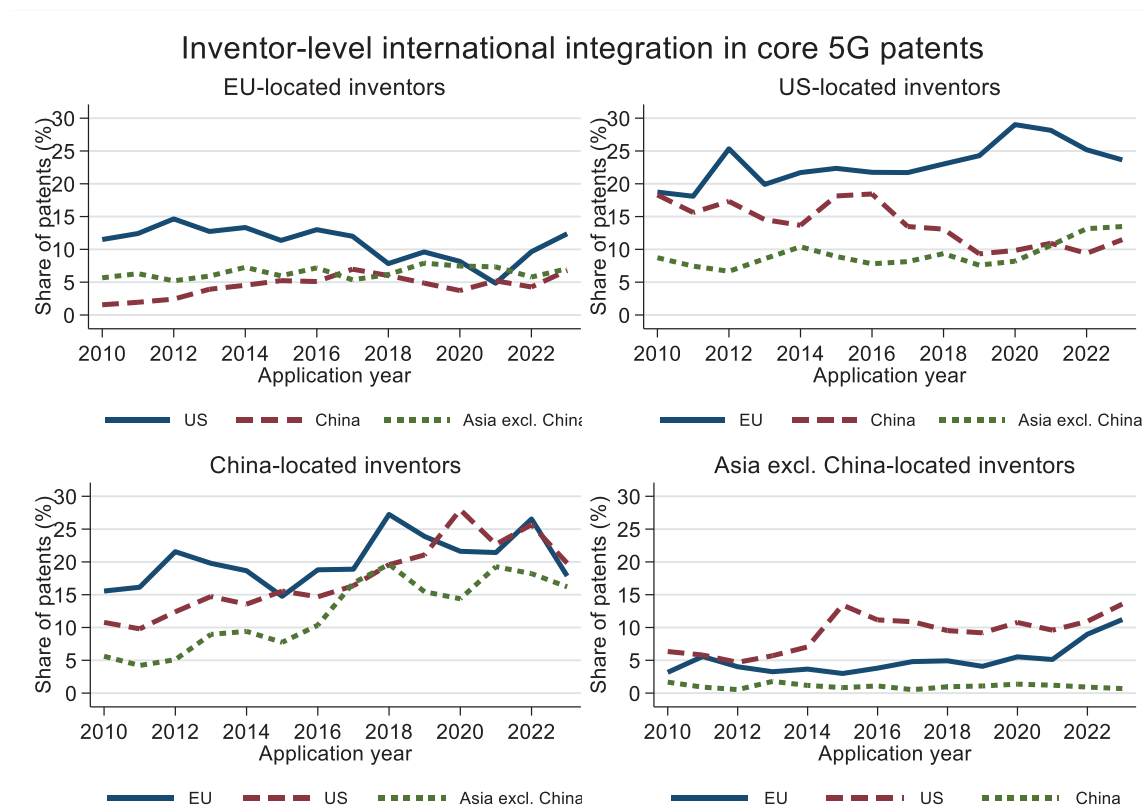


Figure 2 reports inventor-level integration, measured as the share of patents involving at least one inventor located outside the focal firm's headquarters geographical bloc. In contrast to the sharp decline in cross-bloc co-application shown in Figure 1, inventor-level integration remains substantial throughout the sample period. Patents assigned to U.S., European, and Chinese firms frequently involve inventors located in other blocs, with shares often ranging between 10 and 30 percent. Although some series exhibit moderate declines or shifts over time, multinational inventor networks remain considerably more prevalent than formal co-application relationships do.

Taken together, the descriptive evidence suggests that international integration in core 5G technologies occurs primarily through inventor networks rather than through jointly owned patents. The empirical analysis that follows examines whether firms with stronger pre-existing cross-bloc integration adjusted their collaboration networks more strongly as geopolitical fragmentation intensified.

Figure 2. Cross-Bloc Inventor Integration in Core 5G Technologies



4. Empirical strategy

We estimate the effect of geopolitical fragmentation on cross-bloc inventive collaboration using a continuous shift-share exposure design. We classify inventor locations into four geopolitical blocs: the United States, the European Union and the United Kingdom, China, and other Asia. Cross-bloc collaboration refers to patents involving inventors located in both Western economies (the U.S. or EU/UK) and China. Identification comes from cross-sectional differences in firms' pre-period exposure to headquarters-specific cross-bloc inventor mixing in 5G and time-series variations in the global decline of cross-bloc co-invention.

Specifically, we construct firm-level exposure measures based on pre-period collaboration patterns from 2010 to 2011. Our baseline exposure measure is headquarters-specific and captures firms' pre-period reliance on cross-bloc inventor integration between Western economies and China. For firms headquartered in the EU/UK and the United States, exposure is measured using EU–China and U.S.–China inventor mixing, respectively. For firms headquartered in China and other Asian economies, exposure is measured using West–China inventor mixing, where the Western bloc comprises inventors located in the United States and the EU/UK. Inventor mixing is defined as the product of inventor shares across the respective blocs and therefore increases when inventors from both blocs contribute more intensively to

the same patents. Because the exposure measure is defined prior to the escalation of geopolitical tensions, it is predetermined with respect to subsequent fragmentation dynamics.

To capture the time variation in geopolitical fragmentation, we construct annual shocks based on changes in cross-bloc co-invention intensity outside the focal firm sample. Specifically, we use first-priority patent families from the Patent Inspiration database and compute annual cross-bloc co-invention shares after excluding all firms in the estimation sample. Shocks are defined relative to patenting activity in the relevant geopolitical bloc and are matched to firms based on their headquarters location. For firms headquartered in the EU/UK and the United States, the shocks capture changes in EU–China and U.S.–China co-invention intensity. For firms headquartered in China and other Asian economies, the shocks capture changes in China–West co-invention intensity, as measured from the Chinese side of the collaboration network. Therefore, the resulting shocks reflect changes in the broader cross-bloc co-invention environment without incorporating the patenting activity of focal firms. Before constructing the Bartik exposure, the annual changes in cross-bloc co-invention intensity are multiplied by -1 so that higher values correspond to stronger geopolitical fragmentation and then standardized to have a mean of zero and unit variance.

Our baseline reduced-form specification is

$$Y_{ipt} = \beta(Exposure_i \times Shock_t) + \mu_i + \lambda_t + \varepsilon_{ipt} \quad (1)$$

where Y_{ipt} measures different dimensions of cross-bloc inventor integration on patent (p) filed by firm (i) in year (t). We focus on two complementary dimensions of cross-bloc inventor integration: conflict-bridge collaboration and inventor bloc diversity. Conflict-bridge collaboration captures the existence of inventor links spanning the China–West geopolitical divide, and inventor bloc diversity captures the extent to which inventive activity is distributed across geopolitical blocs. The baseline analysis additionally examines U.S.–China and EU–China inventor bridges, which decompose cross-bloc collaboration into its two principal bilateral channels, as well as the conflict-bloc inventor share, which captures the intensive-margin composition of inventor teams. Inventor-bloc diversity is measured as $1 - HHI$, where the Herfindahl–Hirschman Index is calculated using inventor shares across the five geopolitical blocs (United States, EU/UK, China, Asia excluding China, and the rest of the world). Higher values indicate more geographically diversified inventor teams.

Firm fixed effects (μ_i) absorb time-invariant differences in firms' technological portfolios, baseline international orientation, and collaboration strategies, while application-year fixed effects (λ_t) control for aggregate shocks common to all firms (e.g., technology-specific developments). The standard errors are clustered at the firm level.

Identification follows the logic of shift–share designs: the geopolitical shock varies over time and is assigned according to firms' headquarters location, while exposure varies across firms and is fixed in the pre-period. Therefore, the coefficient β is identified from differential within-

firm adjustments that are proportional to firms' prior dependence on cross-bloc knowledge recombination. Intuitively, when cross-bloc co-invention declines globally, firms that previously relied more heavily on EU–China, U.S.–China, or broader China–West inventor integration should experience larger adjustments in the geographic composition of their inventor teams. The key identifying assumption is that, in the absence of geopolitical fragmentation, firms with different levels of pre-period exposure would not have exhibited systematically different trends in inventive collaboration within core 5G technologies.

Several features of the empirical setting strengthen this assumption. First, exposure is measured clearly before the observed decline in cross-bloc co-invention intensity, limiting concerns about anticipatory adjustment. Second, the analysis is confined to core 5G technologies, mitigating concerns regarding cross-industry compositional shifts. Third, firm fixed effects ensure that identification relies on within-firm adjustments rather than cross-sectional differences in the level of internationalization. Year fixed effects absorb common macroeconomic, technological and regulatory shocks.

Importantly, geopolitical fragmentation is not modeled as a discrete policy break but as a continuous and non-linear decline in cross-bloc integration intensity. Therefore, the estimated coefficient captures the reduced-form effect of increasing geopolitical friction on the organization of inventive collaboration among frontier 5G firms. These estimates should be interpreted as reflecting the combined consequences of export controls, regulatory tightening, and strategic decoupling, which altered the expected returns to cross-bloc knowledge recombination.

As an additional validation exercise, we estimate an event-study specification that interacts the pre-period exposure measure with application-year indicators. The analysis focuses on conflict-bridge collaboration and inventor bloc diversity, which summarize two complementary dimensions of cross-bloc inventor integration. The year 2018 serves as the final pre-fragmentation benchmark before the escalation of U.S.–China technology tensions over 5G infrastructure. This specification allows us to assess whether firms with different levels of pre-period exposure exhibited differential pre-trends prior to the intensification of geopolitical frictions and to trace how the relationship between exposure and cross-bloc inventor integration evolved over time. Together, the baseline shift–share specification and the event-study analysis provide a framework for identifying how geopolitical fragmentation reshapes inventive collaboration networks in frontier 5G technologies.

5. Estimation results

Table 2 reports the baseline reduced-form estimates of the relationship between geopolitical fragmentation and cross-bloc collaboration. The coefficient of interest captures the interaction between firms' pre-existing exposure to cross-bloc inventor integration and the annual variation in global cross-bloc co-invention. In a shift–share (Bartik) interpretation, the estimates

measure how firms with different levels of pre-period cross-bloc integration adjust their inventor networks as the global co-invention environment becomes more fragmented.

The results indicate a systematic decline in cross-bloc inventor integration among firms that were more exposed to such collaboration before the intensification of geopolitical fragmentation. A one-standard-deviation increase in the exposure–shock interaction is associated with a 2.2 pp decline in the probability of conflict-bridge collaboration and a 2.1 pp decline in the probability of a U.S.–China inventor bridge. These effects are economically meaningful, given that the average probabilities of conflict-bridge and U.S.–China bridge collaboration are approximately 9 and 8 percent, respectively. In contrast, the estimated effect on EU–China inventor bridges is small and statistically insignificant.

Table 2. Baseline effects of geopolitical fragmentation on cross-bloc innovation collaboration

	(1) Conflict bridge	(2) US-CN bridge	(3) EU-CN bridge	(4) Conflict-bloc inventor share	(5) Diversity
Exposure × fragmentation shock (std)	-0.022*** (0.005)	-0.021*** (0.006)	-0.005 (0.003)	-0.011** (0.004)	-0.018*** (0.004)
Constant	0.091*** (0.000)	0.085*** (0.000)	0.025*** (0.000)	0.095*** (0.000)	0.087*** (0.000)
Observations	106117	106117	106117	106117	106019
R-squared	0.110	0.117	0.064	0.115	0.128

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The results further suggest that geopolitical fragmentation affects the broader composition of inventor teams. Firms with greater pre-period exposure experienced a decline in the share of inventors located in rival geopolitical blocs and a reduction in inventor-bloc diversity. Because inventor diversity captures the distribution of inventors across the five geopolitical blocs, a negative coefficient indicates a decline in the geographic heterogeneity of inventive teams. Taken together, these findings suggest that geopolitical fragmentation reduces not only the incidence of cross-bloc inventor collaboration but also the diversity of inventor networks within frontier 5G innovation.

Table 3 examines whether the effects of geopolitical fragmentation differ across firms headquartered in different geopolitical blocs. The estimates reveal substantial heterogeneity in the reconfiguration of the inventor networks.

Table 3. Bloc-specific heterogeneity in responses to geopolitical fragmentation

	(1) Conflict bridge	(2) Conflict-bloc inventor share	(3) Diversity
EU: Modified exposure × fragmentation shock (std)	-0.192* (0.095)	-0.538*** (0.127)	-0.022 (0.120)
US: Modified exposure × fragmentation shock (std)	0.030 (0.020)	-0.015 (0.019)	0.019 (0.028)
China: Modified exposure × fragmentation shock (std)	-0.018*** (0.006)	-0.012** (0.005)	-0.014*** (0.005)
Asia (excl-CN): Modified exposure × fragmentation shock (std)	-0.022*** (0.007)	-0.028** (0.012)	-0.018* (0.010)
Constant	0.085*** (0.011)	0.046*** (0.014)	0.093*** (0.013)
Observations	106117	106117	106019
R-squared	0.111	0.116	0.129

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Chinese firms exhibited the most consistent adjustment patterns. Greater exposure to fragmentation shocks is associated with a statistically significant decline in cross-bloc inventor bridges, a reduction in the share of inventors from rival geopolitical blocs, and a decrease in inventor bloc diversity. Taken together, these results indicate a broad decline in cross-bloc inventor integration among Chinese frontier firms as geopolitical fragmentation intensifies.

Firms headquartered in other Asian economies display a similar but less pronounced pattern. More exposed firms experience statistically significant declines in cross-bloc inventor bridges and the share of inventors from rival geopolitical blocs. Although inventor diversity also exhibits a negative coefficient, the estimate is only marginally statistically significant. Overall, the results suggest that fragmentation affects the geopolitical composition of inventor networks in other Asian economies, although the adjustments are less pronounced than those observed among Chinese firms.

For firms headquartered in the European Union, the strongest effect appears in the composition of the inventor teams. More exposed firms exhibit a substantial decline in the share of inventors from rival geopolitical blocs, whereas the estimated reduction in cross-bloc inventor bridges is only marginally statistically significant. In contrast, the diversity of inventors

remains broadly unchanged. This pattern suggests a reconfiguration rather than a contraction of inventor networks, whereby collaboration with inventors from rival geopolitical blocs is reduced without a corresponding decline in the overall geographic diversity of inventive teams.

In contrast, firms headquartered in the United States exhibit little systematic response across the three measures. None of the estimated coefficients is statistically distinguishable from zero, suggesting that more exposed U.S. firms were able to maintain the structure and diversity of their inventor networks despite the broader decline in cross-bloc co-invention documented in the aggregate data.

Figures 3 and 4 show the event study estimates for conflict-bridge collaboration and inventor-bloc diversity, respectively. Together, these figures capture two complementary dimensions of cross-bloc inventor integration. Conflict-bridge collaboration measures whether inventors from opposing geopolitical blocs collaborate within the same patent, and inventor bloc diversity captures the overall distribution of inventors across geopolitical blocs. The figures plot year-specific coefficients for the interaction between firms' pre-period exposure to cross-bloc inventor integration, measured in 2010–2011, and the application-year indicators. Estimates are reported relative to the reference year 2018, immediately preceding the escalation of U.S.–China technological tensions.

The event study estimates reveal no systematic pre-trend patterns. For both outcomes, the pre-fragmentation coefficients are generally small and statistically indistinguishable from zero, indicating that firms with different levels of exposure followed similar trajectories prior to the intensification of geopolitical tensions. This pattern is consistent with the identifying assumption underlying the shift–share design.

Figure 3. Event-Study Estimates: Conflict-Bridge Collaboration

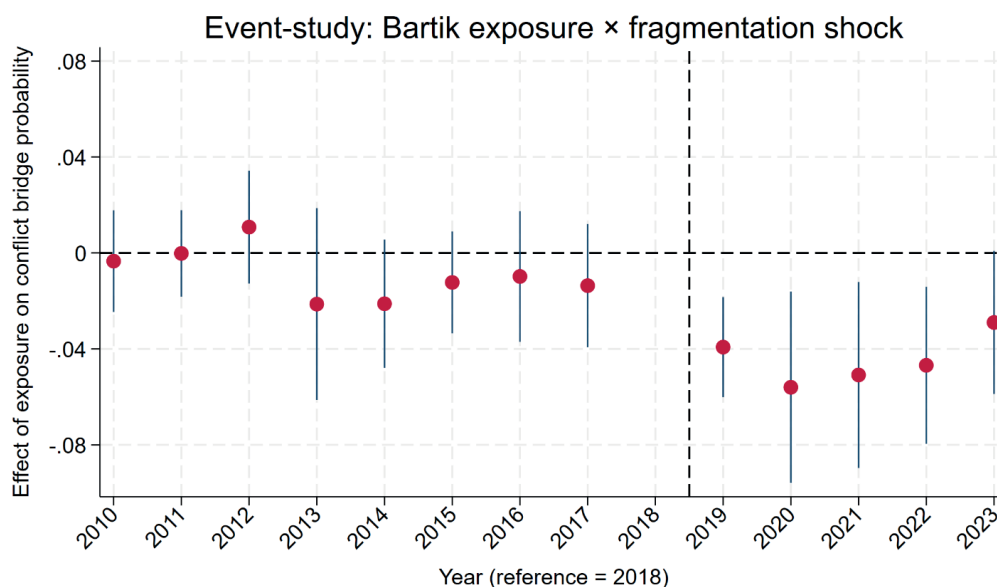
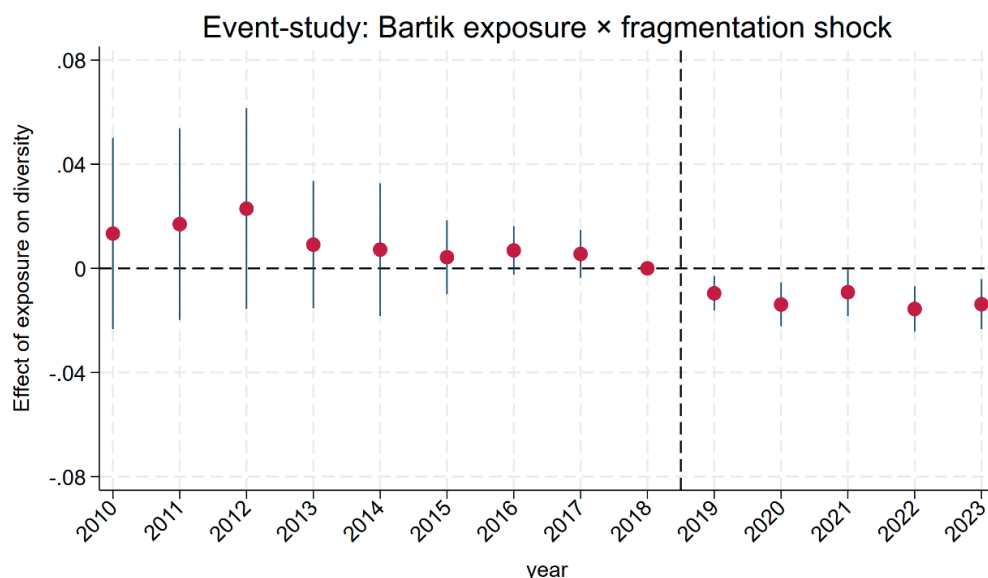


Figure 4. Event-Study Estimates: Inventor Bloc Diversity



After 2018, the estimated effects were negative for both measures. Firms with greater pre-existing exposure to cross-bloc inventor integration experience a decline in the probability of conflict-bridge collaboration and a reduction in inventor bloc diversity. The effects on conflict-bridge collaboration are sizeable and particularly pronounced between 2020 and 2022. Inventor-bloc diversity also declined persistently after 2018, indicating that geopolitical fragmentation affected not only the formation of cross-bloc inventor links but also the broader geographic composition of inventive teams. Overall, the event study evidence supports the interpretation that the baseline results reflect the effects of geopolitical fragmentation rather than pre-existing differences in collaboration patterns across firms.

The event study evidence reinforces the interpretation of the baseline findings. The absence of systematic pre-trends suggests that firms with different levels of pre-period exposure to cross-bloc inventor integration followed similar trajectories prior to the intensification of geopolitical tensions. However, after 2018, firms with greater exposure experienced a decline in conflict-bridge collaboration and, to a lesser extent, in inventor bloc diversity. These patterns are consistent with the view that geopolitical fragmentation contributed to the reorganization of cross-bloc innovation networks rather than merely reflecting preexisting differences across firms.

6. Conclusions

This study examines how rising geopolitical tensions reshape inventive collaboration in a strategically important and standard-setting technology: core 5G infrastructure. Using 106,117 priority patent applications filed between 2010 and 2023 by leading 5G firms, we analyze how

geopolitical fragmentation affects cross-bloc inventor networks linking China and Western economies.

To identify the effects of fragmentation, we employed a shift–share (Bartik) design that combines firms’ pre-period exposure to cross-bloc inventor integration with annual changes in global cross-bloc co-invention intensity. The results provide consistent evidence that geopolitical fragmentation reduces cross-bloc inventor integration within frontier 5G innovation. Firms that relied more heavily on cross-bloc inventor mixing before the escalation of geopolitical tensions experienced larger declines in cross-bloc collaboration when the broader co-invention environment became more fragmented.

These effects are evident across multiple dimensions of inventor-network integration. Firms that were more exposed experienced a lower probability of conflict-bridge collaboration and U.S.–China inventor bridges, a decline in the share of inventors located in rival geopolitical blocs, and a reduction in inventor-bloc diversity. These findings indicate that geopolitical fragmentation affects not only the existence of cross-bloc inventor links but also the broader geographic composition of inventive teams.

Responses were heterogeneous across geopolitical blocs. Chinese firms exhibit the broadest and most systematic reductions in cross-bloc inventor integration, while firms headquartered in other Asian economies display similar but weaker adjustments. European firms primarily reduce the participation of inventors from rival geopolitical blocs without a comparable decline in overall diversity. In contrast, U.S. firms show little systematic change across the examined measures. Together, these patterns suggest that geopolitical fragmentation reshapes inventor networks in ways that depend on firms’ positions within the global innovation system.

Event study estimates further strengthen the interpretation of the baseline findings. We find no evidence of systematic differential pre-trends prior to the intensification of U.S.–China technological tensions. Following 2018, however, firms with greater pre-period exposure experienced persistent declines in both conflict-bridge collaboration and inventor bloc diversity. These dynamics support the view that the estimated effects reflect the consequences of geopolitical fragmentation rather than pre-existing differences in collaboration patterns across firms.

More broadly, the results demonstrate that geopolitical fragmentation influences innovation not only through trade, investment, or supply chain channels but also through the organization of knowledge production itself. A large body of literature emphasizes the importance of geographically diverse knowledge sources and cross-border recombination for innovative activity. Our findings show that geopolitical fragmentation reduces the forms of cross-bloc interaction that facilitate access to heterogeneous knowledge pools. Although the present study does not identify the consequences of these network changes for innovation outcomes, prior research suggests that restrictions on cross-border knowledge recombination may have long-run implications for the direction and effectiveness of innovative activity.

These findings have implications for both innovation management and technology policy. For firms, geopolitical risk is not only a question of market access or supply chain resilience but also a constraint on the composition of R&D teams and the international networks through which complementary expertise is accessed. For policymakers, the results highlight a potential trade-off: measures aimed at technological security and sovereignty may contribute to the fragmentation of inventor networks that have historically facilitated cross-border knowledge exchanges. As strategic competition increasingly shapes the global technology landscape, understanding how geopolitical boundaries influence innovation organization will become an increasingly important research and policy challenge.

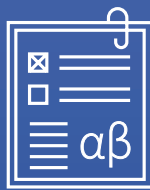
While this study documents how geopolitical fragmentation reshapes inventor networks, it does not directly examine the consequences of these changes for broader innovation outcomes. Future research could examine whether fragmentation-induced changes in cross-border collaboration affect patent quality, technological impact, and long-run innovative performance. Additional work could explore the mechanisms through which firms adapt to geopolitical fragmentation, including alternative forms of collaboration and organizational responses. An important avenue for future research is also to assess whether similar inventor network effects emerge in other strategically important technologies, such as semiconductors, artificial intelligence, and quantum technologies.

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