

Technology, Geopolitics, and Trade[‡]

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October 2025

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Abstract

We study *when* unilateral export controls are optimal by quantifying how geopolitical rivalry reshapes trade in ideas. Empirically, cross-border *technology* flows are far more sensitive than goods trade to geopolitical distance, especially where IPR is weak, and these penalties intensify after 2017. Motivated by this evidence, we build a growth–trade model in which geopolitical distance raises breach risk in licensing; firms partially reprice risk via higher royalties but cannot fully insure quantities. In a consumption-only benchmark, a permanent rise in US–China geopolitical distance yields modest net gains for the United States, implying no benchmark motive for controls. Once governments place weight on *national security*, measured as relative technological leadership, controls can be welfare-improving despite efficiency costs. When the probability of Chinese retaliation rises with control tightness, the optimal policy is strictly interior (tighter than laissez-faire yet below a full ban).

JEL classification: F63, O14, O33, O34.

Keywords: Geopolitics, international trade, strategic rivalry, technology transfer.

*The views in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of St. Louis or the Federal Reserve System.

[†]We thank Doireann Fitzgerald, Esteban Rossi-Hansberg, and Mike Waugh for insightful comments. We are grateful to seminar participants at the Minneapolis Fed, the University of Michigan, the Chicago Fed, and the 2025 Society for Economic Dynamics. We also thank Ankit Patro for excellent research assistance. Contact information: Lam: Academia Sinica, E-mail: leochlam.research@gmail.com; Santacreu: Federal Reserve Bank of Saint Louis, E-mail: am.santacreu@gmail.com.

1 Introduction

In recent decades, the international trading system was shaped by a proliferation of deep trade agreements that extended well beyond the traditional focus on tariff reduction. These agreements systematically incorporated provisions on intellectual property rights (IPR), aimed at curbing imitation and misappropriation of foreign technologies. The resulting enforcement mechanisms reduced the risk of expropriation faced by innovators, supporting cross-border licensing and facilitating the global diffusion of ideas. Comparative advantage and efficiency considerations governed the allocation of production, while technological spillovers across borders reinforced innovation-driven growth.

The current geopolitical environment marks a departure from this cooperative framework. Governments increasingly rely on unilateral policy instruments designed to restrict technology flows, particularly across geopolitical fault lines. Export controls, foreign investment screening, and the creation of blacklists have become central tools of industrial and national security policy. The intensity of these interventions has risen dramatically since 2022, with technology-related restrictions emerging as a core dimension of great-power rivalry, most notably between the United States and China. By the end of 2024, governments had implemented 116 distinct geopolitically motivated restrictions on technology, with roughly 84% directed at China (Figure 1). These interventions span critical technological domains, including semiconductors, artificial intelligence, and quantum computing, reflecting the increasingly explicit linkage between technological leadership and national security in international economic policy.

Geopolitical rivalry reshapes cross-border technology transfer. As geopolitical distance widens, firms internalize thinner market access, higher contractual fragility, and the prospect of regulatory shifts. The resulting reallocation of idea flows away from politically distant pairs and toward safer partners impacts who learns from whom, the speed at which ideas diffuse globally, and the distribution and pace of innovation-led growth. Against this background, the relevant policy question is not whether to use export controls, but *when* an intervention is justified and *how* intensive it should be once efficiency costs and strategic responses are taken into account. In particular, policies that restrict technology flows must be evaluated relative to their effects on domestic innovation incentives, international spillovers, and the likelihood of retaliation; a general implication is that the optimal policy balances security objectives against the losses from reduced market access and knowledge diffusion. In this paper, we first document how geopolitical distance interacts with institutional quality to shape international technology flows, and then develop a quantitative framework to assess when and how export controls should be used in light of these trade-offs.

Empirically, we document that geopolitical tensions disrupt the international diffusion of technology primarily when they coincide with weak domestic institutions. Where

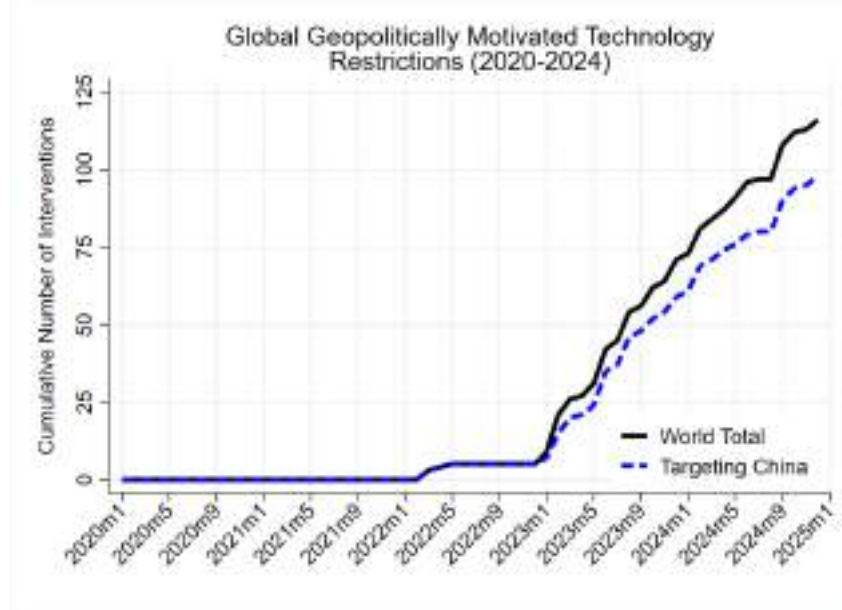


Figure 1: Global Geopolitically Motivated Technology Restrictions (2020–2024). The figure shows the cumulative number of policy interventions targeting technology exports with explicit geopolitical motivations. Data source: GTA NIPO (2024), distortive policies targeting exports in advanced technology sectors.

IPR enforcement is weak, political tensions sharply reduce technology inflows, undermining diffusion and raising barriers to innovation. By contrast, in environments with strong IPR protections, the effect of political tensions on technology transfer is muted, as robust institutions safeguard contractual enforcement and reduce appropriation risk. In this sense, geopolitical fragmentation is not uniform: it is particularly strong at the intersection of high political rivalry and weak institutional environments. This interaction highlights the central role of institutional quality in mediating the extent to which geopolitical rivalry reshapes global patterns of trade, technology transfer, and ultimately growth.

Motivated by this evidence, we develop a multi-country endogenous growth model of trade and technology transfer that incorporates both geopolitical frictions and institutional quality. In the model, countries are linked both through trade in differentiated intermediate goods and through cross-border technology licensing. Innovators invest in R&D to develop new blueprints, while foreign adopters decide whether to license these technologies legitimately or to breach contracts and imitate them. Licensing terms are determined through Nash bargaining, with geopolitical distance raising the probability of contractual breach. Strong IPR enforcement reduces these risks, while weak IPR institutions amplify them.

A central asymmetry arises in how geopolitical distance affects different forms of cross-border exchange. For merchandise trade, geopolitical distance matters primarily through standard gravity channels: political tensions reduce trade flows by raising bilateral trade

costs. These lower trade flows, in turn, shrink the potential market size for licensing technologies abroad. For technology transfer, however, geopolitical distance has an additional effect by directly increasing the probability of breach in licensing relationships. As a result, technology diffusion is doubly exposed to political frictions: once indirectly, through reduced market size, and once directly, through higher breach risk. Because innovators earn profits only when contracts are honored, while adopters can benefit under both compliance and breach, the wedge created by political tensions is inherently more severe for technology flows than for trade flows. The strength of IPR enforcement governs the magnitude of this asymmetry, mitigating the impact of geopolitical distance when institutions are strong and amplifying it when institutions are weak.

For tractability, we model the risk of breach as an exogenous function of geopolitical distance and institutional quality. This reduced-form specification captures the central empirical regularity we document: the sensitivity of technology flows to geopolitical rivalry depends systematically on IPR enforcement, while preserving the existence of a Balanced Growth Path.¹ We view our formulation as a disciplined first step that isolates the novel interaction between geopolitics and IPR enforcement, while remaining analytically tractable and directly tied to the data.

The model also highlights a divergence between private and policy objectives. Licensors and adopters choose contracts to maximize the present value of *private* licensing returns, but they do not internalize how idea flows affect the country’s *relative* technology position. By contrast, the government values household consumption *and* national security, which we operationalize as relative technological leadership (the gap in technology stocks with respect to rivals). We therefore formulate the policy problem with an augmented objective that combines consumption-equivalent welfare and a leadership component, with partner-specific weights that can be higher for geopolitical rivals and destinations with weak IPR enforcement. In this environment, technology restrictions such as export controls can be rational even when they reduce aggregate consumption, because they help preserve technological advantage that private contracts do not internalize.

Geopolitical rivalry in our paper means political misalignment that increases the cost of cross-border technology contracting. Rivalry shows up in two ways: It makes it harder to enforce licensing agreements (higher breach risk) and it indirectly shrinks market size through lower bilateral integration, both of which depress enforceable royalty flows and weaken innovation and technology diffusion. In the empirical analysis, we operationalize this concept using the interaction of geopolitical distance with the importer’s IPR strength, capturing that misalignment matters most where enforcement is weak. In the model, rivalry is the primitive that increases breach risk and contracting frictions and

¹Endogenizing breach or imitation behavior, for example by allowing adopters or governments to allocate resources to enforcement, would be a natural extension (Lam, 2024; Hémous et al., 2023).

amplifies effective barriers to exchange; IPR quality mediates how strongly these political frictions translate into lost, enforceable technology flows.

Our paper makes three main contributions. First, we provide empirical evidence that the impact of geopolitical distance on technology transfer is conditional on institutional quality, with weak IPR regimes amplifying fragmentation. Second, we develop a structural framework to study the effect of geopolitical tension and heterogeneous IPR institutions on technology and trade flows. Third, we extend the literature on geoeconomics by explicitly formalizing the augmented government objective: governments maximize discounted consumption but also value relative technological leadership. This approach connects our analysis to recent work on optimal tariffs with geopolitical alignment (Becko, Grossman, and Helpman, 2025), theories of geoeconomic power (Clayton, Maggiori, and Schreger, 2025b), and the emerging economics of innovation under security concerns (Chatterji and Murray, 2025).

We quantify the model by calibrating it to data on trade flows, royalties, R&D intensity, patents, and citations across 8 regions: the United States, the Euro Area, Mexico, Canada, South Korea, Japan, China, and an aggregate rest of the world. The calibration covers the period 2000–2017, a phase of relatively low geopolitical tensions, and then introduces a post-2017 increase in geopolitical rivalry. We analyze transitional dynamics, measure welfare costs in consumption-equivalent units, and evaluate unilateral technology export controls under both a standard (consumption-only) objective and an *augmented* objective that also places weight on national security, measured as relative technological leadership (the US–China technology gap), with results reported both with and without retaliation risk. This quantitative exercise allows us to assess how geopolitical fragmentation reshapes trade, technology diffusion, and innovation across multiple regions, and to examine under what conditions government intervention becomes welfare-improving once national security considerations are taken into account. We find that under the consumption-only objective (and under a security motive without strategic risk), the policy objective is essentially monotone and delivers corner solutions, whereas allowing the probability of retaliation to increase with control intensity induces sufficient curvature for a strictly interior maximizer—one that rises with the weight on national security yet remains below a full ban.

Placing our findings in the broader literature clarifies the novelty of this mechanism. Recent work has emphasized geopolitical alignment as a determinant of cross-border flows (Becko, Grossman, and Helpman, 2025; Clayton, Maggiori, and Schreger, 2025b,c). Firm-level evidence also documents adjustment to geoeconomic pressure, including R&D responses to U.S. semiconductor controls (Clayton et al., 2025). Other contributions highlight the fusion of economic and security considerations in the emerging “economics of innovation” (Chatterji and Murray, 2025). Our results complement these insights:

we show empirically that fragmentation is not driven by political distance in isolation, but rather by its interaction with institutional quality. This evidence motivates the augmented government objective that we develop in the model section. While firms optimally set licensing terms to internalize contractual breach risk, they do not internalize the broader strategic externality associated with the erosion of relative technological leadership. By embedding a bilateral technology-gap term into the government’s welfare function, weighted by geopolitical distance and IPR strength, our framework provides a micro-founded rationale for the very types of technology restrictions that have proliferated in recent years. In this sense, the empirics and the theory speak directly to one another: the evidence documents the interaction of geopolitics and IPR in shaping global technology flows, and the model explains why governments, unlike firms, would have an incentive to intervene even when private contracts appear efficient.

Literature Review This paper connects to several strands of literature studying international trade and technology flows under strategic tensions. First, it contributes to emerging research on how geopolitical frictions affect economic relationships. While standard trade models focus on geographic distance and policy barriers, our framework incorporates how political tensions impact both trade costs and technology contracting risk. Aiyar, Presbitero, and Ruta (2023) provides an overview of both empirical and quantitative studies that examine the impacts of geoeconomic fragmentation across trade, technology, and financial channels.

The paper’s empirical findings extend the gravity literature in international economics by documenting systematic differences in how trade and technology flows respond to political tensions. Our empirical methodology follows state-of-the-art gravity methods from Yotov et al. (2016) and Baier, Yotov, and Zylkin (2019). Our key result that royalty payments exhibit greater sensitivity to political distance than conventional trade flows, especially in relationships with weak IP protection, provides motivation for our theoretical mechanisms. We build on Santacreu (2025)’s analysis of technology licensing by modeling how contract enforcement probability varies with political distance and institutional quality.

The paper’s quantitative analysis of how IPR interacts with political distance to determine technology diffusion patterns is related to research studying developing country IP reforms (Branstetter, Fisman, and Foley, 2006; Glass and Saggi, 1999). Lam (2024) develops a dynamic general equilibrium model in which countries strategically choose their level of IPR enforcement, balancing the trade-offs between imitation and innovation. Our paper is related in that both examine the role of IPR enforcement in shaping international technology transfer and innovation. However, we differ by incorporating geopolitical factors, specifically political distance, as a determinant of technology licensing and trade, highlighting how strategic considerations influence firms’ decisions beyond IPR policy

alone.

We also contribute to research on strategic trade policy and technology controls. While earlier work like Helpman (1993) studied IP protection’s effects on innovation and welfare, we analyze how countries optimally set technology transfer restrictions based on geopolitical relationships and institutional environments. This connects to recent work by Hémous et al. (2023) on patent policy in the global economy, although we focus specifically on how bilateral political tensions shape technology flows through their impact on contracting risk. Hémous et al. (2023) develop a quantitative trade-and-growth model to study optimal patent protection across countries. While their focus is on the classic innovation–market power trade-off and the welfare implications of international coordination over patent policy, we highlight a complementary dimension: how geopolitical rivalry interacts with institutional quality to shape technology licensing and diffusion.

Our paper is also related to Becko and O’Connor (2024) in that we examine how geopolitical considerations shape economic policy. While we focus on technology transfer and intellectual property rights, Becko and O’Connor (2024) studies trade and industrial policy as tools for geopolitical leverage. Unlike their paper, we highlight how political distance influences firms’ licensing decisions and the enforcement of international contracts.

Our paper speaks to a growing literature on geoeconomics, technology transfer, and state-contingent policy. Recent theory highlights how geopolitical alignment shapes cross-border flows and strategic policy design (Clayton, Maggiori, and Schreger, 2025a,c), while firm-level evidence documents adjustments to geoeconomic pressure, including R&D responses to U.S. semiconductor export controls (Clayton et al., 2025). Complementary work on the diffusion margin shows how multinational investment and joint ventures can accelerate technology transfer and intensify global competition (Choi et al., 2025). On the policy side, state-dependent technology policy can shift from adoption to innovation as followers catch up (Choi and Shim, 2024), and strategic (dis)integration frameworks formalize how governments balance openness and control along geopolitical lines (TBA, 2025). We contribute by quantifying a specific mechanism, geopolitical distance interacting with IPR to raise breach risk in licensing, linking it to observed sensitivities of technology flows, and using it to study when unilateral export controls are (constrained) optimal once national-security considerations and retaliation risk are taken into account.

Our work complements Bai et al. (2025), who study optimal dynamic trade policies in an Eaton-Kortum model with technology diffusion through trade. While they examine how trade patterns affect the distribution from which potential producers draw insights, we focus on how geopolitical distance affects contract enforcement and licensing decisions. Unlike their approach, which emphasizes how governments manipulate trade policies to influence the diffusion of technology across countries, we highlight the role of private

contracting decisions in response to political frictions. Similarly, our work differs from Bai, Jin, and Lu (2023), who analyze technological rivalry and optimal dynamic policy in an open economy with endogenous R&D. Their model focuses on how a country can strategically influence foreign innovation efforts through trade and innovation policies, even in the absence of externalities. In contrast, our framework explicitly incorporates geopolitical tensions as a determinant of cross-border technology transfer and shows that weak intellectual property (IP) enforcement amplifies these effects. While Bai, Jin, and Lu (2023) derive optimal trade and innovation policies based on a government’s ability to manipulate foreign incentives, we study how firms internalize geopolitical risk when setting royalty rates and making licensing decisions.

Additionally, our work connects to Kleinman, Liu, and Redding (2024), who examine how economic interdependence shapes political alignment. Their findings demonstrate that increased trade exposure to a country leads to closer political alignment, a mechanism we incorporate into our framework by analyzing how geopolitical tensions alter technology licensing decisions and intellectual property governance. While their study focuses on broad measures of economic and political integration, we provide a more granular analysis of how these forces operate through international technology markets and contractual enforcement.

Finally, while alternative mechanisms such as FDI and quid pro quo practices (Holmes, McGrattan, and Prescott, 2015) offer important insights into technology diffusion, these channels often implicitly assume substantial firm-specific investments or reciprocal market-entry conditions, which may not fully capture the complexity of incremental, contract-based technology transfers and ongoing innovation dynamics. Our framework can also be interpreted through the lens of FDI: in this view, breach risk corresponds to the probability of expropriation, forced technology transfer in joint ventures, or adverse regulatory interventions that erode affiliates’ control of proprietary knowledge. Geopolitical distance would raise the likelihood of such risks, while strong IPR regimes would mitigate them, making the basic mechanisms of our model applicable to FDI-based technology diffusion.

However, we emphasize licensing as the more natural setting for our analysis. Licensing arrangements, structured around bargaining processes and periodic royalty schemes, are explicitly designed to manage dynamic uncertainties and evolving market conditions characteristic of international technology diffusion. This bargaining-based framework highlights contractual frictions, transaction costs, and innovation incentives that are central to real-world technology licensing but less explicitly addressed within FDI-centric or quid pro quo frameworks. Moreover, licensing offers a clearer empirical window, since royalty and license fee payments provide a direct measure of cross-border knowledge flows, whereas FDI combines capital reallocation, tax motives, and technology transfer in ways that are difficult to disentangle. Finally, recent policy interventions, such as

export controls, blacklists, and restrictions on technology licensing, have operated primarily through licensing channels, underscoring their strategic relevance. Thus, while our framework admits an FDI interpretation, grounding it in licensing provides both sharper microfoundations and a more direct connection to current policy debates.

The remainder of the paper is organized as follows. Section 2 presents the empirical evidence on the relationship between geopolitical distance, trade flows, and technology transfer. Section 3 develops the quantitative model and characterizes its equilibrium properties. Section 4 analyzes the BGP and the mechanisms through which geopolitical tensions affect economic outcomes. Section 5 presents the welfare function, augmented to account for national-security concerns. Section 6 conducts counterfactual policy analysis. Section 7 concludes with policy implications and directions for future research.

2 Empirical Strategy

In this section, we empirically analyze the impact of geopolitical distance on merchandise trade and cross-border technology transfers. We proxy technology transfers with receipts of royalty and license fees, which capture formal, contract-based flows of technological know-how.

Our dataset covers bilateral flows between 44 countries from 2000 to 2021, a period that includes the intensification of geopolitical tensions following the escalation of US–China technology rivalry and Russia’s increasing divergence from Western economies. Merchandise trade data come from BACI-CEPII, which harmonizes customs records worldwide, while royalty and license fee flows are drawn from the OECD International Trade in Services statistics. Geopolitical distance is measured using the ideal-point distance between countries in UN General Assembly voting, following Bailey, Strezhnev, and Voeten (2017) and adapted by Airaud et al. (2025). To capture persistent patterns of foreign policy alignment rather than short-term fluctuations, we average this measure over the post-2017 period.

As a key conditioning variable, we include the strength of IPR protection in the importing country, measured by the International Property Rights Index (0–100, Property Rights Alliance). Stronger IPR regimes mitigate risks of expropriation or unauthorized use of foreign technologies, potentially moderating the effect of political misalignment on cross-border transactions. Additional controls include standard gravity variables from CEPII (log geographic distance, contiguity, common language, and trade agreements). Exporter–year and importer–year fixed effects absorb unobserved time-varying country characteristics and multilateral resistance terms.

We estimate the following structural gravity equation using Poisson Pseudo-Maximum

Likelihood (PPML):

$$Y_{ijt} = \exp(\beta_1 \log GP_{ij} + \beta_2(\log GP_{ij} \times IPR_j) + \beta_3 IPR_j + \beta_4 X_{ijt} + \delta_{it} + \gamma_{jt}) \varepsilon_{ijt}, \quad (1)$$

where Y_{ijt} denotes either bilateral merchandise exports or royalty payments from exporter i to importer j in year t , $\log GP_{ij}$ measures geopolitical distance, IPR_j is the IPR index in the importing country, and X_{ijt} is the vector of gravity controls. The interaction term allows us to test whether the adverse effect of geopolitical distance is moderated in high-IPR environments.

Table 1: Impact of Geopolitical Distance and IPR on Trade and Royalties (PPML, 2007–2021)

	No IPR Interaction		With IPR Interaction	
	Trade	Royalties	Trade	Royalties
Log Geopolitical Distance	-0.022*** (0.006)	0.089*** (0.015)	-0.103*** (0.019)	-0.455*** (0.048)
Geo $\times$ IPR	–	–	0.135*** (0.028)	0.761*** (0.071)
Observations	24,276	26,082	24,276	26,082

Standard errors clustered at the country-pair level in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Dependent variable: bilateral merchandise trade flows (columns 1 and 3) or royalty and license fee flows (columns 2 and 4).

Log Geo Distance: bilateral UNGA ideal-point distance (Bailey et al.).

Geo $\times$ IPR: interaction with the importer’s International Property Rights Index (0–1, PRA).

Estimation method: Poisson Pseudo-Maximum Likelihood (PPML) with exporter–year and importer–year fixed effects.

Table 1 reports the estimates. In the baseline specification without the IPR interaction (columns 1 and 2), geopolitical distance exerts a small but statistically significant negative effect on merchandise trade (−0.022), while it shows a puzzling positive and significant association with royalty flows (0.089). This positive coefficient is unexpected, as geopolitical rivalry would normally be expected to deter cross-border licensing and technology diffusion.

Two complementary mechanisms may account for this pattern. First, a *composition effect* arises because a small subset of geopolitically distant but high-IPR destinations—such as Ireland, the Netherlands, or Switzerland—account for a disproportionate share of global royalty flows. In these pairs, observed royalties may reflect profit-shifting practices and the booking of intangible income in low-tax jurisdictions, rather than genuine technology diffusion. Second, a *price effect* operates through contract renegotiation: innovators facing higher perceived political or enforcement risk may charge higher royalty fees ex ante to compensate for potential breach or uncertainty. Both mechanisms inflate the aggregate value of recorded royalties even when the quantity of legitimate technology transfers declines.

Consistent with this interpretation, when the interaction with IPR protection is introduced (columns 3 and 4), the underlying relationship becomes clearer. For royalties, the

coefficient of geopolitical distance turns negative and is statistically significant (-0.455), while the large and positive interaction term (0.761) indicates that stronger IPR regimes substantially mitigate the adverse effect of political misalignment. In contrast, merchandise trade also becomes more negatively associated with geopolitical distance (-0.103), but the moderating effect of IPR is relatively modest (0.135).

The interaction term captures both of the complementary mechanisms discussed above. On the one hand, it controls for the *composition effect* by allowing high-IPR destinations—often high-income and low-tax economies—to differ in how geopolitical distance shapes observed royalty payments. Once institutional strength is taken into account, the positive baseline coefficient no longer reflects the overrepresentation of geopolitically distant but good IPR pairs in aggregate royalty flows. On the other hand, the interaction also captures the *price effect*: in countries with stronger IPR enforcement, exporters can credibly price political and contractual risk into higher royalty fees without reducing the quantity of legitimate transactions. By contrast, in weak-IPR environments, higher geopolitical distance raises breach risk and induces exporters to charge higher royalty fees, but these contractual adjustments only partially offset the higher probability of noncompliance. As a result, total legitimate technology transfers decline.

We also examine whether these relationships change over time by splitting the sample into the pre-2017 and post-2017 periods. The detailed results, reported in Appendix A, suggest that geopolitical frictions became more pronounced in recent years, consistent with the escalation of trade and technology tensions after 2017.

While the reduced-form regressions provide robust evidence that geopolitical distance and IPR protection interact in shaping international flows, they do not in themselves reveal the mechanisms behind these relationships. The patterns raise several questions: Why are technology flows more sensitive than goods trade to geopolitical tensions? Through what channels do IPR regimes alter the strategic calculus of exporters in politically distant markets? Under what conditions can strong institutions fully neutralize the deterrent effect of political misalignment, and when do they fall short? To answer these questions, we develop a structural model in which exporters choose whether to license technology or export goods based on both geopolitical and institutional conditions, and where these choices feed back into aggregate flows.

3 Model

Based on our empirical evidence, we develop a model that captures the interaction between geopolitical tensions, intellectual property enforcement, and international technology transfer. There are M countries in the world economy, indexed by i and n . Time is discrete and indexed by t .

Each country has four types of agents. Final goods producers combine traded intermediate varieties under perfect competition. Intermediate producers are monopolistic competitors and produce differentiated varieties using labor. Innovators develop new blueprints for intermediate varieties through R&D investment, and adopters decide whether to implement these foreign technologies legitimately by paying royalties or attempt to imitate them without compensation. The interaction between innovators and adopters is governed by Nash bargaining over licensing terms, which determines the royalty rate and the extent of legitimate technology transfer. Intermediate goods are traded and face iceberg transport costs.

Two key frictions shape these relationships. First, geopolitical distance raises both trade costs and technology transfer barriers by increasing the risk of contract breach. Second, IP enforcement determines the degree of protection that innovators receive against contract breach, influencing the incentives for both licensing and imitation. These frictions create barriers for trade flows, royalty payments, and knowledge transfers through both legitimate and illegitimate channels, leading to strategic responses by firms.

3.1 Household

Each country admits a representative household that maximizes the lifetime utility

$$U_{n,t} = \sum_{s=t}^{\infty} \beta^{s-t} \ln(C_{n,s}), \quad (2)$$

where β is the discount factor and $C_{n,s}$ is the consumption of country n at time s , subject to the budget constraint

$$P_{n,t}C_{n,t} + P_{n,t}B_{n,t+1} = W_{n,t}L_{n,t} + \Pi_{n,t}^{all} + P_{n,t}R_tB_{n,t} + IBT_{n,t}, \quad (3)$$

where $P_{n,t}$ is the price index, $W_{n,t}$ is the wage, $L_{n,t}$ is the labor endowment, $\Pi_{n,t}^{all}$ is the total profits of all firms in country n , and $B_{n,t}$ is the one-period risk-free bond that is traded internationally at world interest rate R_t . The last term $IBT_{n,t}$ is the lump-sum transfer from the government generated from tariff revenue. The household consumes, invests, supplies labor inelastically, and owns all firms.

3.2 Final Production

In each country, there is a final good $Y_{n,t}$ produced under perfect competition with a constant elasticity of substitution ($\sigma > 1$) production function

$$Y_{n,t} = \left(\sum_{i=1}^M \int_{j=1}^{T_{it}} x_{ni,t}(j)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}} \quad (4)$$

where $x_{ni,t}(j)$ is the intermediate input j demanded by country n and produced from country i at time t ; T_{it} is the mass of intermediate goods produced in country i . This yields the demand for intermediate goods:

$$x_{ni,t}(j) = \left(\frac{p_{ni,t}(j)}{P_{n,t}} \right)^{-\sigma} Y_{n,t} \quad (5)$$

where $p_{ni,t}(j)$ is the respective price for an intermediate input j from country i paid by country n . And the aggregate price index $P_{n,t}$ can be derived as

$$P_{n,t} = \left(\sum_{i=1}^M \int_{j=1}^{T_{it}} p_{ni,t}(j)^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}} \quad (6)$$

3.3 Intermediate Production

Assume there is a continuum of monopolistic competitive intermediate producers. They produce good j with a linear production function

$$y_{n,t}(j) = \Omega_{nt} l_{n,t}(j), \quad (7)$$

where Ω_{nt} is the country-specific productivity and $l_{n,t}(j)$ is the labor inputs hired by that firm. Given the input demand, the intermediate producer maximizes profits

$$\pi_{nt}(j) = \sum_{i=1}^N p_{in,t}(j) x_{in,t}(j) - W_{nt} l_{nt}(j) \quad (8)$$

3.4 International Trade

Intermediate goods are traded internationally. Trade is costly because of: (i) tariff $\tau_{in,t}$ levied on imports, and (ii) iceberg transport cost d_{in} , which can be generalized as $d_{in} = (d_{in}^G)^{\kappa^G} (d_{in}^P)^{\kappa^P}$. Different from the traditional settings, our specification breaks down this barrier into two sources which are *geographical distances* and *political distances*. This specification allows us to calibrate the responsiveness of trade flows to these two measures

of distances. We can derive the import share as

$$s_{ni,t} = \frac{\Omega_{it}^{\sigma-1} T_{it} (W_{it} d_{ni} (1 + \tau_{ni,t}))^{1-\sigma}}{\sum_{m=1}^N \Omega_m^{\sigma-1} T_{mt} (W_{mt} d_{nm} (1 + \tau_{nm,t}))^{1-\sigma}} \quad (9)$$

3.5 Innovation

In each country n , a monopolist invests H_{nt}^R units of final production to introduce a new idea or technology. The number of new technologies invented is given by

$$\Delta Z_{nt} = \lambda_n Z_{nt}^w \left(\frac{H_{nt}^R}{Y_t} \right)^{\beta^R}, \quad (10)$$

where $\Delta Z_{nt} = Z_{n,t+1} - Z_{nt}$, and Z_{nt} is the stock of invented technologies. The term $\lambda_n Z_{nt}^w$ represents innovation efficiency, where λ_n is a country-specific innovation productivity parameter, and Z_{nt}^w captures global knowledge spillovers. In particular,

$$Z_{nt}^w = \sum_{i=1}^M \gamma_{ni} Z_{it},$$

where Z_{it} is the stock of technologies invented in country i , and $\gamma_{ni} \in [0, 1]$ is a weight that reflects the ease with which ideas from i diffuse to n . These weights are taken as exogenous. The key point is that Z_{nt}^w measures the set of ideas that reach country n through diffusion, regardless of whether they are adopted for production. In other words, it is the global “knowledge pool” accessible to n at time t , which shapes the productivity of domestic innovation efforts even before considering adoption decisions.

The term $\bar{Y}_t = \sum_{m=1}^M Y_{mt}$ is world output, and $\beta^R \in (0, 1)$ reflects diminishing returns to innovation. An innovator chooses $H_{n,t}^R$ to maximize

$$V_{nt}(Z_{n,t+1} - Z_{nt}) - P_{nt} H_{nt}^R, \quad (11)$$

where V_{nt} is the value of an innovation, to be defined later.

Ideas are blueprints that can be used in the production of differentiated intermediate goods. These ideas must be adopted prior to their use, as described below.

3.6 Adoption and Technology Licensing

In each country, adopters invest resources to adopt technologies created elsewhere. We assume a unit-measure continuum of ex-ante identical adopters $j \in [0, 1]$ who face i.i.d. compliance shocks with hazard $\phi(d_{in,t}^P)$, to be defined later. By the law of large numbers, we normalize cohort size to one and omit the j index, interpreting all variables as cohort averages.

Adoption is costly and uncertain. Adopters in country i can invest $H_{in,t}^A$ units of final output to adopt a technology invented in country n . The probability of successful adoption is given by

$$\epsilon_{in,t} = \bar{\epsilon}_{in} \left(\frac{H_{in,t}^A}{\bar{Y}_t} \right)^{\beta^A}, \quad (12)$$

where $\bar{\epsilon}_{in}$ is the adoption productivity parameter, $\beta^A \in (0, 1)$ captures diminishing returns to adoption, and $H_{in,t}^A$ is the amount of final output that adopters in country i invest to adopt technologies from country n .

The number of technologies adopted by country i , invented in country n , evolves according to

$$\Delta A_{in,t} = \epsilon_{i,n,t} (Z_{nt} - A_{in,t}), \quad (13)$$

where a fraction $\epsilon_{in,t}$ of the unadopted technologies $(Z_{nt} - A_{in,t})$ is adopted in period $t + 1$.

The total stock of knowledge in country n is the sum of all technologies adopted from different countries:

$$T_{nt} = \sum_{i=1}^M A_{ni,t}. \quad (14)$$

Technology Licensing Upon successful adoption, adopters use each technology j to produce a differentiated intermediate good. Adopters pay royalties to innovators for the rights to exploit the technology in production. The licensing arrangement is modeled as a fixed-rate, $\eta_{in,t}$, profit-sharing contract. The licensing rate $\eta_{in,t}$ is determined by Nash bargaining at time t , maximizing the joint surplus of innovators and adopters:²

$$\operatorname{argmax}_{\eta_{in,t}} (V_{in,t}^{\text{Innov}})^{\rho_{in}} (V_{in,t}^{\text{Adopt}})^{1-\rho_{in}}, \quad (15)$$

where ρ_{in} is the innovator's bargaining power and $V_{in,t}^{\text{Innov}}$ ($V_{in,t}^{\text{Adopt}}$) denotes the continuation value to the innovator (adopter) from licensing the technology, to be defined formally below.

Geopolitical tensions impact the negotiation process through a probability of breach, $\phi(d_{in}^P, \text{IPR}_n) \in [0, 1]$, which depends on geopolitical distance and the adopter country's IPR protection. We assume $\partial\phi/\partial d_{in}^P > 0$ and $\partial\phi/\partial \text{IPR}_n < 0$, i.e., greater geopolitical distance raises enforcement risk, whereas stronger IPR lowers it by increasing expected legal remedies, court enforceability, and reputational/market-access penalties. This breach risk

²In the symmetric equilibrium, all technologies face the same royalty fee $\eta_{in,t} \forall j$.

enters the continuation values $V_{in,t}^{Innov}$ and $V_{in,t}^{Adopt}$ below and, through Nash bargaining, affects the equilibrium royalty rate $\eta_{in,t}$ and the surplus split.

One might argue that if technology licenses are paid entirely upfront, the risk of contract breach becomes irrelevant. In practice, however, even lump-sum agreements typically prohibit resale or unauthorized diffusion to other firms. In our model, the innovator licenses the technology to a continuum of potential adopters in the destination country. An upfront payment by one adopter represents only a fraction of the total potential market. A breach, interpreted here as leakage of the technology to unauthorized adopters, eliminates the possibility of selling to the remaining continuum of firms, thereby reducing payments to innovators. In this sense, our profit-sharing specification is consistent with both per-period royalty contracts and upfront payments, since in both cases the innovator's expected revenue stream depends critically on preventing leakage to unauthorized adopters.

The innovator's value function satisfies

$$\begin{aligned} V_{in,t}^{Innov} &= \eta_{in} \pi_{in,t} + \frac{P_{n,t}}{R_t P_{n,t+1}} (1 - \phi(d_{in}^P)) V_{in,t+1}^{Innov} \\ &= \eta_{in} \Upsilon_{in,t}, \end{aligned}$$

where $\pi_{in,t}$ are profits that adopters in country i make with technologies developed in country i and $\Upsilon_{in,t}$ is the discounted value of future profits from licensing when the contract remains compliant.

The adopter's value when the contract is in force is

$$\begin{aligned} V_{in,t}^{Adopt} &= (1 - \eta_{in}) \pi_{in,t} + \frac{P_{i,t}}{R_t P_{i,t+1}} \left[(1 - \phi(d_{in}^P)) V_{in,t+1}^{Adopt} + \phi(d_{in}^P) V_{in,t+1}^{Breach} \right] \\ &= (1 - \eta_{in}) \Upsilon_{in,t} + \Upsilon_{in,t}^{Breach}, \end{aligned}$$

where $\Upsilon_{in,t}^{Breach}$ is the continuation value associated with the breach.

Finally, once a breach occurs, the adopter receives the full profit flow in perpetuity:

$$V_{in,t}^{Breach} = \pi_{in,t} + \frac{P_{i,t}}{R_t P_{i,t+1}} V_{in,t+1}^{Breach}.$$

Both $\Upsilon_{in,t}$ and $\Upsilon_{in,t}^{Breach}$ are determined endogenously by the enforcement hazard $\phi(d_{in}^P)$ and the underlying profit stream $\pi_{in,t}$.

The royalty fee The optimal royalty fee derived from equation (15) becomes:

$$\eta_{in,t} = \rho_{in} \left[1 + \frac{\Upsilon_{in,t}^{Breach}}{\Upsilon_{in,t}} \right], \quad (16)$$

where the first term inside brackets represents breach compensation and the second represents the adjustment due to contracting costs.

Innovators pass on a relatively larger share of transaction costs to adopters through higher royalty fees. However, innovators cannot fully raise royalty fees to completely internalize higher breach probabilities. This limitation results in royalty fees that are lower than would ideally compensate innovators for the elevated risk.

3.7 Optimal Innovation and Adoption

Before the invention is adopted, its value to the innovator is given by

$$J_{in,t}^{Innov} = \frac{1}{R_t} \frac{P_{i,t}}{P_{i,t+1}} [\epsilon_{in,t} V_{in,t+1}^{Innov} + (1 - \epsilon_{in,t}) J_{in,t+1}^{Innov}] \quad (17)$$

With probability $\epsilon_{in,t}$, this invention is adopted next period and gives the value of $V_{in,t+1}^{Innov}$. With probability $1 - \epsilon_{in,t}$, it remains unadopted and gives the continuation value $J_{in,t+1}^{Innov}$.

The value of an unadopted invention to an adopter is

$$J_{in,t}^{Adopt} = -P_{it} h_{in,t}^A + \frac{1}{R_t} \frac{P_{i,t}}{P_{i,t+1}} [\epsilon_{in,t} V_{in,t+1}^{Adopt} + (1 - \epsilon_{in,t}) J_{in,t+1}^{Adopt}] \quad (18)$$

where $h_{in,t}^A$ is the investment to adopt technology j .

It shares a similar structure as the value of the unadopted invention to the innovator. The difference is that an adopter pays an R&D cost on adoption $P_{it} h_{in,t}^A$. Summing equation 17 across adopting countries, we obtain the total value of an innovation invented in country n :

$$V_{n,t} = \sum_{i=1}^N J_{in,t}^{Innov} \quad (19)$$

In a symmetric equilibrium, every technology j generates the same value and aggregation leads to the following FOC for innovation and adoption (Santacreu, 2025).

The first-order condition for optimal innovation is

$$P_{n,t} H_{n,t}^R = \beta^R (Z_{n,t+1} - Z_{n,t}) V_{n,t} \quad (20)$$

Using equation 17, the first-order condition for optimal adoption is

$$P_{i,t} h_{in,t}^A = \beta^A \epsilon_{in,t} \frac{P_{i,t}}{R_t P_{i,t+1}} (V_{in,t+1}^{Adopt} - J_{in,t+1}^{Adopt}) \quad (21)$$

and the total adoption expenditure is given by

$$H_{in,t}^A = h_{in,t}^A (Z_{n,t} - A_{in,t-1}) \quad (22)$$

3.8 Market Clearing Conditions

The final good is used for consumption, innovation, and adoption. Output market clearing implies

$$Y_{nt} = C_{nt} + H_{nt}^R + \sum_{i=1}^M H_{ni,t}^A \quad (23)$$

Labor is supplied inelastically and is used for the production of intermediate goods. Labor market clearing implies

$$L_{nt} = \sum_{i=1}^M T_{nt} \frac{x_{int} d_{in} (1 + \tau_{int})}{\Omega_{nt}} = \sum_{i=1}^M T_{nt} \frac{\sigma - 1}{\sigma} p_{int} x_{int} \quad (24)$$

$$\Rightarrow \frac{\sigma}{\sigma - 1} W_{nt} L_{nt} = \sum_{i=1}^M \frac{s_{int}}{1 + \tau_{int}} P_{it} Y_{it}. \quad (25)$$

When tariffs are positive, the revenue generated is redistributed to the household as a lump sum given by

$$IBT_{nt} = \sum_{i \neq n} \frac{\tau_{nit}}{1 + \tau_{nit}} s_{nit} P_{nt} Y_{nt}. \quad (26)$$

Balance of Payments requires that the net export value equals net royalty payments, given by

$$\sum_{i \neq n} \frac{s_{nit} P_{nt} Y_{nt}}{1 + \tau_{nit}} + \sum_{i \neq n} RP_{nit} = \sum_{i \neq n} \frac{s_{int} P_{it} Y_{it}}{1 + \tau_{int}} + \sum_{i \neq n} RP_{int} \quad (27)$$

where the royalty payment for technology invented in country n and adopted by country i is defined as

$$\begin{aligned} RP_{in,t} = & \underbrace{\eta_{in,t} \left(\frac{A_{in,t} - A_{in,t-1}}{T_{it}} \right) \Pi_{it}}_{\text{new cohort}} + \underbrace{\sum_{s=1}^{t-1} \eta_{in,t-s} \prod_{k=1}^s (1 - \phi(d_{in,t-k+1}^P)) \left(\frac{A_{in,t-s} - A_{in,t-s-1}}{T_{it}} \right) \Pi_{it}}_{\text{older cohorts (compliant)}} \\ & + \underbrace{\eta_{in,0} \prod_{k=1}^t (1 - \phi(d_{in,t-k+1}^P)) \left(\frac{A_{in,0}^L}{T_{it}} \right) \Pi_{it}}_{\text{initial stock (compliant)}}. \end{aligned} \quad (28)$$

This equation shows that royalty payments consist of two main components: (i) royalties from newly adopted technologies in period t , using the current royalty rate $\eta_{in,t}$, (ii) royalties from previously adopted technologies whose contract has not yet been breached, which utilize historical royalty rates $\eta_{in,t-s}$ combined with cumulative contract survival probabilities that now explicitly depend on evolving geopolitical distance through $(1 - \phi(d_{in,t-k+1}^P))$ terms, and (iii) royalties from the pre-existing legitimate stock $A_{in,0}^L$ that survives through t with probability $\prod_{k=1}^t (1 - \phi(d_{in,t-k+1}^P))$ and pays at the initial rate $\eta_{in,0}$.

3.9 Equilibrium

Given the initial vector $\{A_{in,0}, Z_{n,0}\}$, an equilibrium is defined as a sequence of aggregate prices and wages $\{P_{nt}, W_{nt}, R_t\}_{t=0}^\infty$, a sequence of intermediate prices $\{p_{in,t}\}_{t=0}^\infty$, a sequence of royalty fees $\{\eta_{in,t}\}_{t=0}^\infty$, a sequence of value functions $\{V_{in,t}^A, V_{in,t}^I, J_{in,t}^A, J_{in,t}^I, V_{in,t}^B, V_{n,t}\}_{t=0}^\infty$, a sequence of profits and payments $\{\Pi_{nt}, RP_{in,t}\}_{t=0}^\infty$, a sequence of quantities $\{Y_{nt}, H_{nt}^R, H_{in,t}^A, s_{in,t}\}_{t=0}^\infty$, and a sequence of technology stocks $\{A_{in,t+1}, Z_{n,t+1}\}_{t=0}^\infty$ such that:

- (i) $\{A_{in,t+1}, Z_{n,t+1}\}_{t=0}^\infty$ satisfy the law of motion (13) and (10);
- (ii) Given prices, allocations maximize consumer utility (2) subject to budget constraint (3);
- (iii) Given prices, allocations solve the final good producer's problem, yielding equation (5);
- (iv) Given prices, allocations solve the intermediate good producers' problems (8) subject to demand (5);
- (v) Given prices, allocations solve the innovators' and adopters' decisions, consistent with equation (20) and (21);
- (vi) The royalty fees are determined as the result of Nash bargaining defined in (15);
- (vii) Feasibility condition is satisfied in (23);
- (viii) Prices clears all markets in equation (24), (26), and (27).

4 Balanced Growth Path

We define the BGP as an equilibrium in which aggregates grow at a common constant rate while *relative* objects are stationary. To characterize it, we stationarize the model so that relative variables are time invariant. In this representation the BGP is summarized

by a stationary vector of relative technology stocks $\{\hat{T}_n^*\}$ and a common growth rate g^* . The pair $(g^*, \{\hat{T}_n^*\})$ solves the fixed-point relation

$$g^* \hat{T}_i^* = \sum_{n=1}^M \underbrace{\frac{\epsilon_{in}^*}{\epsilon_{in}^* + g^*}}_{\text{adoption factor}} \lambda_n \left(\frac{\hat{Z}_n^{w*}}{\hat{T}_n^*} \right) \left(\frac{H_n^{R*}}{\hat{Y}^*} \right)^{\beta^R} \hat{T}_n^* \equiv \sum_n \Delta_{in}(g^*; \epsilon^*) \hat{T}_n^*.$$

Equivalently,

$$g^* \hat{T}^* = \Delta(g^*) \hat{T}^*,$$

where $\Delta(g^*)$ includes adoption intensities and innovation productivity evaluated on the stationary allocation. Under indecomposability, Perron–Frobenius implies a unique positive eigenvalue g^* and an associated eigenvector $\{\hat{T}^*\}$.

Comparative statics: higher geopolitical distance. A permanent rise in geopolitical distance d_{ni}^P affects the BGP through two blocks of the model. First, it enters bilateral trade costs, compressing bilateral market access and the licensable demand relevant for innovators (i.e., the flow of legitimate adoptions); this is the *market-size channel*. Second, it raises the breach hazard $\phi(\cdot)$ in the licensing block, which changes the compliant-path value Υ and the breach continuation Υ^{Breach} , and hence the negotiated royalty fee $\eta_{in} = \rho_{in} [1 + \Upsilon_{in}^{\text{Breach}} / \Upsilon_{in}]$; this is the *breach channel*. When both channels operate, the BGP displays lower adoption between the countries with higher geopolitical distance, higher royalty *rates* but lower royalty *payments* due to smaller compliant quantities, weaker innovation effort in the leader, and a decline in the BGP growth rate, g^* . The relative technology position of the leader deteriorates because the growth contribution from its R&D block falls faster than the follower’s catch-up through remaining idea flows.

Two decompositions in the Appendix help interpret these forces. In a first exercise, we shut down the market-size effect of geopolitics in the trade block (keeping geography and policy wedges fixed there) and let d^P operate only through breach. In that case, adoption does not collapse and higher η reallocates surplus toward the innovator; the compliant-path value is protected, innovation incentives for the leader strengthen, and relative technological leadership can *improve* even though contracts become riskier. In a second exercise, we insulate breach (strong IPR in the destination) and let d^P act only through market size. Adoption probability and royalties barely change, but the smaller licensable market compresses the innovator’s return, reducing BGP research intensity and the common growth rate; leadership is impacted negatively through the innovation margin. These two experiments show that the decline in growth and leadership in the baseline occurs when both channels are active: demand for licensed ideas decreases and a larger fraction of the surviving flow is exposed to breach, so raising the royalty rate cannot fully insure the innovator’s dynamic payoff. The growth margin is primarily disciplined

by market size. The decompositions show that the *market-size channel* (via lower s_{ni} and $\pi_{in,t}$) is what materially compresses the compliant-path value $\Upsilon_{in,t}$, reduces the licensable adoption flow, and lowers $H_n^R/\bar{Y}$, thereby pulling down g^* . The *breach channel* on its own does not collapse adoption, but it raises $\Upsilon_{in,t}^{\text{Breach}}/\Upsilon_{in,t}$ and pushes up $\eta_{in,t}$, which only partially reallocates surplus to innovators.

5 Welfare Analysis

We now turn to the welfare implications of introducing geopolitical distance into our framework.

Our starting point is the standard objective in which the government cares only about household consumption. Welfare is evaluated in consumption-equivalent units, defined as the compensating variation required to make households indifferent between (i) remaining in the original equilibrium path without geopolitical shock, and (ii) transitioning to the new BGP, accounting for the entire adjustment path. Formally, welfare $\mathcal{W}$ is defined implicitly by

$$\sum_{t=0}^{\infty} \beta^t u((1 + \mathcal{W})C_{\text{original},t}) = \sum_{t=0}^{\infty} \beta^t u(C_{\text{transition},t}),$$

where $C_{\text{original},t}$ and $C_{\text{transition},t}$ denote consumption in the original equilibrium path and along the new transition path, respectively.

An equivalent expression for the welfare loss, λ_n , is

$$\lambda_n = \exp((1 - \beta)(W_n^{\text{new}} - W_n^{\text{old}})) - 1,$$

with W_n^{new} and W_n^{old} representing discounted utility under the new and old regimes. This benchmark provides the conventional measure of efficiency costs from geopolitical frictions.

Augmented Government Objective: Strategic Considerations While global technology diffusion increases aggregate innovation, governments may also value their *relative* technological position with respect to specific partners. A narrowing bilateral technology gap can increase competitive pressures in strategic sectors and create national security risks. Private firms do not internalize these broader costs, as their licensing decisions reflect only private profits. By contrast, governments may place explicit value on preserving technological leadership, particularly against geopolitically distant or weak-IPR countries. This introduces a wedge between private and social objectives and provides a formal rationale for interventionist policies such as export controls.

Formally, let i denote the home country and $n \neq i$ a trading partner. If Z_{jt} denotes the technology level of country j at time t , the government's objective function is given

by

$$\mathcal{W}_i = \sum_{t=0}^{\infty} \beta^t \left[u(C_{it}) + \theta \sum_{n \neq i} \gamma_{in} g\left(\frac{Z_{it}}{Z_{nt}}\right) \right], \quad (29)$$

where:

- $u(C_{it})$ is per-period utility from aggregate consumption;
- $\theta > 0$ captures the weight placed on strategic considerations;
- $\gamma_{in} = h(d_{in}^P)(1 - \text{IPR}_n)^\xi$ is a bilateral weight, increasing in geopolitical distance d_{in}^P and sensitive to IPR enforcement in country n ;
- $g(\cdot)$ is an increasing function mapping relative technology into welfare units, with $g(x) = \log x$ in the baseline.

This augmented formulation highlights that even if firms fully internalize breach risks in licensing contracts, a wedge remains: firms focus on private returns, whereas governments care about relative technological gaps. The wedge provides a natural rationale for government interventions aimed at preserving technological advantage against geopolitically distant partners.

Our augmented welfare formulation builds on a growing literature that incorporates geopolitical motives into government objectives. Becko, Grossman, and Helpman (2025) show that optimal tariffs emerge when governments value not only consumption but also the alignment of trading partners, leading to an additive geopolitical term in welfare. Similarly, Clayton, Maggiori, and Schreger (2025b) formalize preferences that combine economic payoffs with geopolitical alignment, embedding non-economic considerations directly into welfare. More broadly, Chatterji and Murray (2025) argue that the fusion of economic and security concerns has given rise to a new “economics of innovation,” where governments pursue economic security by shaping the direction of innovation.

6 Quantitative Analysis

In this section, we conduct a quantitative analysis to examine how geopolitical tensions affect technology transfers and trade. We calibrate the model to data on trade flows, royalty payments, R&D intensity, patent and citations data, and other standard gravity and macroeconomic variables. We group our sample of countries into 8 regions—the United States, the Euro Area, Mexico, Canada, South Korea, Japan, China, and an aggregate rest of the world—for the period 2000–2020.

We begin by calibrating the model along a transition path covering the period 2000–2020, a phase characterized by relatively low geopolitical tensions. This baseline allows us to match key moments in the data under conditions of stable geopolitical relations. We then

introduce an increase in geopolitical rivalry in 2020 and trace its effects on trade, technology adoption, innovation, and welfare. Welfare is measured in consumption-equivalent units, but to better understand the temporal dynamics we also plot the path of aggregate consumption relative to the initial BGP, hence capturing both the short-run adjustment costs and the long-run consequences of heightened geopolitical tensions.

In the second step, we study the optimal policy responses. We first consider a government that maximizes lifetime household consumption and assess the consequences of implementing unilateral technology export controls. These controls are modeled as bilateral instruments that can be targeted toward specific destination countries. We then extend the analysis by explicitly incorporating national security considerations into the government’s objective function. Specifically, we augment government preferences to depend not only on household consumption, but also on the bilateral technological gap with trading partners. This national security component is weighted by a term that interacts geopolitical distance with the strength of IPR enforcement in the destination country. The resulting formulation captures the idea that national security concerns are more acute vis-a-vis geopolitically distant partners and when IPR protection is weak, hence providing a rationale for welfare-reducing technology export restrictions in some bilateral relationships. The algorithm to solve for the BGP and the transitional dynamics is reported in Appendix C.

6.1 Calibration Strategy

The calibration of the model proceeds in several steps, combining direct data sources, estimates from the literature, and structural regressions. We focus on the period 2000–2020 and the set of WIOT countries augmented with Vietnam. The guiding principle is to use direct data whenever possible, estimate elasticities through gravity regressions, and rely on method-of-moments for the remaining structural parameters.

We begin with parameters that can be directly measured from data. Country labor endowments L_n and expenditure shares are taken from national accounts. Geopolitical distance d_{in}^P is measured using ideal-point distances based on United Nations voting records, while geographical distance d_{in}^G is obtained from CEPII. These quantities are treated as exogenous primitives of the model.

A second set of parameters is borrowed from the literature. We fix the elasticity of substitution across varieties σ , the discount factor β , and the bargaining parameter ρ at values consistent with standard quantitative trade and growth models.

Trade Flows We then estimate the responsiveness of trade flows to distance through a series of structural gravity regressions. Trade flows are taken from the CEPII BACI dataset, and we regress bilateral imports on geographical distance and political distance.

The estimated elasticities deliver values for κ^G and κ^P . The procedure closely follows the state-of-the-art gravity methodology described in Yotov et al. (2016).

Specifically, we estimate gravity with *trade shares* on the left-hand side. Using CEPII BACI, we run

$$\ln s_{in,t} = \alpha_{i,t} + \delta_{n,t} - \kappa^G \ln d_{in}^G - \kappa^P \ln d_{in}^P + \varepsilon_{in,t}, \quad (30)$$

where $s_{in,t} \equiv X_{in,t} / \sum_m X_{mn,t}$ is the import share of n from i in year t , and $\alpha_{i,t}$ and $\delta_{n,t}$ are exporter-year and importer-year fixed effects that absorb multilateral resistance. The distance elasticities κ^G and κ^P map into the bilateral iceberg term

$$d_{in} = (d_{in}^G)^{\kappa^G} (d_{in}^P)^{\kappa^P}, \quad (31)$$

Table 2: Estimated Total Trade Costs d_{in}^{total}

Importer \ Exporter	CAN	CHN	EU	JPN	KOR	MEX	ROW	USA
CAN	–	9.690	5.922	8.552	6.924	5.823	5.037	5.806
CHN	3.403	–	7.984	3.298	2.287	3.956	2.409	6.536
EU	5.304	7.979	–	7.630	5.962	6.356	3.740	9.822
JPN	4.101	4.408	4.282	–	2.962	4.824	3.294	7.918
KOR	4.943	4.596	4.621	2.962	–	5.804	3.781	9.507
MEX	4.090	8.034	5.389	6.982	5.637	–	3.600	6.808
ROW	7.534	9.572	6.246	8.310	6.819	7.755	–	13.663
USA	1.669	5.350	3.316	4.779	3.842	2.774	2.700	–

Notes: Table reports bilateral total trade costs d_{in}^{total} , combining standard iceberg costs and geopolitical costs. Exporters are columns, importers are rows. Diagonal entries are left blank because they correspond to domestic trade.

From the model, bilateral trade shares satisfy

$$s_{in,t} = \frac{\Omega_{i,t}^{\sigma-1} T_{i,t} (W_{i,t} \tilde{d}_{in,t})^{1-\sigma}}{\sum_m \Omega_{m,t}^{\sigma-1} T_{m,t} (W_{m,t} \tilde{d}_{mn,t})^{1-\sigma}}. \quad (32)$$

Comparing (30) and (32), the exporter fixed effect identifies the composite “capability”

$$\alpha_{i,t} \equiv \log S_{i,t} = (\sigma - 1) \log \Omega_{i,t} + \log T_{i,t} + (1 - \sigma) \log W_{i,t} + \text{const}. \quad (33)$$

Given wages $W_{i,t}$ (from the wage/BoP block or national accounts) and the mass of varieties $T_{i,t}$ (from the adoption block), we back out exporter productivity as

$$\Omega_{i,t} = \left(\frac{\exp\{\alpha_{i,t}\} W_{i,t}^{\sigma-1}}{T_{i,t}} \right)^{1/(\sigma-1)}. \quad (34)$$

We pin down the irrelevant constant by a normalization (e.g., $\frac{1}{N} \sum_i \log \Omega_{i,t_0} = 0$ at a

base year or $\Omega_{\text{USA},t_0} = 1$). In practice, we estimate (30) by PPML with exporter-year and importer-year fixed effects, construct bilateral costs via (31), and then recover $\Omega_{i,t}$ using (34).

Table 3: TFP and GDP per Capita Relative to the United States (Backed Out from Gravity)

Region	TFP (USA = 1)	GDP per Capita (USA = 1)
CAN	0.795	0.753
CHN	0.633	0.147
EU	0.713	0.577
JPN	0.847	0.648
KOR	0.784	0.528
MEX	0.574	0.155
ROW	0.470	0.234
USA	1.000	1.000

Notes: TFP and relative GDP per capita are normalized to the United States (=1). TFP is backed out from the gravity regressions, while relative GDP per capita is taken from national accounts, averaged over 2017–2021.

Adoption Probability We calibrate bilateral technology adoption probabilities using international patent citation flows, following the methodology of Caballero and Jaffe (1993) and Cai, Li, and Santacreu (2022). Patent citations are informative about cross-border knowledge flows: when a patent in country d cites prior art from country o , this is evidence that knowledge originating in o has been adopted in d . We interpret the intensity of these citations as a measure of diffusion and map it into an adoption probability.

The data are from INPACT-S, which records the citing and cited inventor’s countries as well as application years. To account for bilateral frictions, we merge in geography variables from CEPII (distance, contiguity, common language) and a measure of geopolitical distance from Bailey, Strezhnev, and Voeten (2017). Intra-country citations are excluded. To absorb time-varying differences in innovation scale, we include fixed effects by origin-year and destination-year.

We then estimate a PPML gravity model of citation flows. Let C_{odt} denote the number of citations from origin o to destination d in year t . The regression takes the form

$$C_{odt} = \exp\left(\beta_1 \ln \text{dist}_{od} + \beta_2 \text{contig}_{od} + \beta_3 \text{comlang}_{od} + \beta_4 \ln \text{geo}_{od} + \alpha_{o,t} + \delta_{d,t}\right) + \varepsilon_{odt}, \quad (35)$$

where $\alpha_{o,t}$ and $\delta_{d,t}$ are the origin-time and destination-time fixed effects. The fitted bilateral index

$$\text{pair}_{od} = \hat{\beta}_1 \ln \text{dist}_{od} + \hat{\beta}_2 \text{contig}_{od} + \hat{\beta}_3 \text{comlang}_{od} + \hat{\beta}_4 \ln \text{geo}_{od}$$

summarizes how geography and geopolitics affect citation intensity.

To map this continuous index into a probability of adoption, we use a logistic transformation,

$$\hat{p}_{od}^{\text{adopt}} = \frac{1}{1 + \exp[-\text{pair}_{od}]}, \quad (36)$$

ensuring values in $(0, 1)$. Next, we interpret adoption as a Bernoulli event occurring within a horizon of L_{od} years, defined as the lag between the cited and citing patents. If ϵ_{od} denotes the per-year adoption hazard, the probability of adoption within L_{od} years is

$$p_{od}^{\text{adopt}} = 1 - \exp(-\epsilon_{od} L_{od}). \quad (37)$$

Equating this to the logistic estimate yields a closed-form calibration of the hazard:

$$\hat{\epsilon}_{od} = -\frac{1}{L_{od}} \ln(1 - \hat{p}_{od}^{\text{adopt}}). \quad (38)$$

Finally, we aggregate these bilateral hazards to the regional level by averaging over all country pairs within each pair of regions. The resulting matrix of hazards $\{\hat{\epsilon}_{od}\}$ forms the adoption block of our quantitative model. This approach ensures that geography and geopolitics directly shape the probability that knowledge produced in one region is adopted in another, consistent with the citation-based measures of diffusion proposed by Caballero and Jaffe (1993) and applied in Cai, Li, and Santacreu (2022).

Table 4: Estimated Adoption Efficiencies ϵ_{in}

Adopter \ Innovator	CAN	CHN	EU	JPN	KOR	MEX	ROW	USA
CAN	0.3300	0.1039	0.0608	0.1678	0.1324	0.0231	0.0505	0.2790
CHN	0.0746	0.3300	0.0360	0.2311	0.1904	0.0066	0.0343	0.2706
EU	0.0403	0.0431	0.3300	0.0703	0.0525	0.0019	0.0136	0.1709
JPN	0.1611	0.1952	0.0779	0.3300	0.2644	0.0210	0.0689	0.2895
KOR	0.1563	0.2000	0.0873	0.2730	0.3300	0.0201	0.0656	0.2888
MEX	0.0145	0.0193	0.0076	0.0581	0.0216	0.3300	0.0049	0.1505
ROW	0.0391	0.0480	0.0221	0.0939	0.0577	0.0033	0.3300	0.1755
USA	0.3144	0.2785	0.2353	0.3147	0.3262	0.1391	0.2013	0.3300

Notes: Table reports estimated bilateral adoption efficiencies ϵ_{in} , where rows correspond to adopters (i) and columns to innovators (n). Diagonal terms are normalized to 0.33, reflecting the assumption that countries adopt their own innovations within three years on average. Off-diagonal terms are estimated using citation-based gravity regressions for the period 2017–2021.

Innovation Innovation parameters are disciplined using patenting and R&D data. We construct patent stocks from annual patent flows using the perpetual inventory method with a depreciation rate of 15%. R&D intensity is taken from the World Bank’s World Development Indicators, expressed as a fraction of world GDP to remain consistent with the model’s scaling. Citation data come from INPACTS (LaBelle et al., 2023) and are

used to calibrate the adoption probabilities ϵ_{in} through gravity regressions, mapping the bilateral probability of knowledge diffusion to political and geographic distances. This step identifies the parameters λ_n , β^R , and β^A , which govern the shape of the innovation and adoption functions. We then regress innovation flows on R&D intensity:

$$\Delta Z_{n,t}/Z_{nt}^w = \lambda_n \left(\frac{RD_{n,t}}{Y_{n,t}} \right)^{\beta^R}, \quad (39)$$

where λ_n is country-specific innovation efficiency (captured by a country-specific fixed effect) and β^R is the curvature parameter of the innovation function.

Table 5: R&D Intensity, Macroeconomic Statistics, Patent Stocks, and Innovation Efficiency (Averages 2017–2021)

Region	R&D Intensity (%)	World GDP (bill. USD)	GDP (bill. USD)	Population (bill.)	Patent Stock	λ_n
CAN	1.8	81,500	1,925	0.038	74,655	0.0139
CHN	2.1	81,500	16,220	1.408	165,891	0.0075
EU	1.8	81,500	20,360	0.520	999,179	0.0064
JPN	2.9	81,500	4,711	0.126	1,066,234	0.0932
KOR	4.3	81,500	1,481	0.052	288,815	0.0375
MEX	0.4	81,500	1,413	0.127	3,209	0.0010
ROW	1.3	81,500	11,670	2.252	475,343	0.0061
USA	3.0	81,500	23,720	0.333	1,049,693	0.0662

Notes: GDP and World GDP are expressed in billions of USD. Population is expressed in billions of people. Patent stocks are reported in raw counts and constructed using a perpetual inventory method with a 15% depreciation rate. All values are averages over 2017–2021. The estimated curvature of the innovation function is $\beta^R = 0.35$.

The remaining set of parameters,

$$\{\gamma, \bar{\epsilon}_{in}, \Omega_n, \kappa^\phi, \phi_0\},$$

are jointly calibrated by a method-of-moments procedure. We target empirical moments that capture both aggregate dynamics and bilateral technology flows:

$$\left\{ \text{Avg}(g_t), \text{Avg}(\epsilon_{in,t}), \text{Avg}(TFP_{in,t}), \hat{\beta}_{RP,GP}, \text{Avg}(\phi_{in,t}) \right\}.$$

The moments include average GDP per capita growth, adoption intensities, TFP dynamics, the reduced-form regression coefficients of royalty payments on geopolitical distance, and the average imitation risk reported by WIPO. Formally, the calibration minimizes the distance between simulated and empirical moments:

$$\min_{\{\Gamma, \kappa^\phi, \bar{\epsilon}_{in}, \Omega_n\}} \|M^{\text{model}} - M^{\text{data}}\|,$$

where M^{model} are model-implied moments and M^{data} their empirical counterparts.

The computational procedure follows a sequence of iterations.

- (i) Guess the BGP values of $\{TFP_n^*, \epsilon_{in}^*, g^*\}$ and set ϕ_0 to match average breach probability. The computed allocation gives $\{\Omega_n, \bar{\epsilon}_{in}, \gamma\}$
- (ii) Set the initial state $Z_{n,0}$ imputed from R&D intensities and patent applications at the first sample period
- (iii) Utilize the imputed Ω_n and the empirical observations of $\epsilon_{in,t}, Z_{n,t}$ to compute the evolution of $A_{in,t}$ and $T_{n,t}$. Set $A_{in,0}$ and $A_{in,0}^L$ imputed from adoption intensities, breach probabilities and patent growth at the initial period.
- (iv) Compute the transition path using the aforementioned algorithm. Compare the simulated path of $TFP_{n,t}$ and $\epsilon_{in,t}$ against the sample. Update $\{TFP_n^*, \epsilon_{in}^*, g^*\}$ and repeat from step (i) until error stabilizes
- (v) Run the gravity regression of $RP_{in,t}$. Compare against empirical estimates to calibrate the remaining variable κ^ϕ .

The calibrated parameters are summarized in the following tables:

Parameters	Description	Value
β	Discount rate	0.96
β^A	Adoption curvature	0.3843
β^R	Innovation curvature	0.3843
σ	Elasticity of Substitution	5
ρ	Innovator's bargaining power	0.25
κ^G	Trade-geography elasticity	1
κ^P	Trade-politics elasticity	0.0132
κ^ϕ	Breach-politics elasticity	0.7250
ϕ_0	Breach probability scaler	0.3010
γ	Innovation scale	4.2107

Param	Description	Value	USA	CAN	MEX	EUR	CHN	JPN	KOR	ROW
λ_i	Innovation efficiency	0.0662	0.0139	0.0010	0.0139	0.0075	0.0932	0.0375	0.0034	
L_i	Labor endowment	1	0.1105	0.3674	1.6440	4.3432	0.4128	0.1607	6.5303	
Ω_i	Productivity	0.3331	0.2832	0.2120	0.2520	0.1901	0.2843	0.2428	0.1672	
ξ_i	IPR enforcement	0.9432	0.9709	0.4535	0.7358	0.1597	0.8686	0.8268	0.5368	

We initialize the state variables (Z_0, A_0, A_0^L) using patent applications, R&D intensities, adoption intensities, breach probabilities and patent stock data. We compute the growth rate of Z_0 from observed patent applications and patent stock between 1996 and 2000, and substitute this into the three laws of motion to back out the ratios Z_0/Z_0^w , A_0/Z_0 , and A_0^L/A_0 . Since the system is homogeneous of degree one, the level of Z_0 is irrelevant and we can normalize Z_0/Z_0^w as the initial condition.

The simulated model produces regression coefficients for $\log(RP_t)$ as a function of geopolitical distance, IPR enforcement, and geography. We align the model-implied coefficients with their empirical counterparts and adjust κ^ϕ (the elasticity of breach to political distance) to minimize the gap, focusing especially on the coefficient of $\log(d^P - 1)$.

	Model	Data
$\log(d^P - 1)$	-0.4050	-0.4050
$\log(d^P - 1) \times \text{IPR}$	0.32206	0.91618
$\log(d^G)$	-0.40282	-2.3978

Table 6: Regression of $\log(RP_t)$ on geopolitical and geographic distance and IPR enforcement: model-implied vs. data coefficients.³

External Validation We assess the external validity of the calibrated model by comparing simulated outcomes to empirical counterparts along a set of untargeted moments.

First, the correlation between model-implied TFP and the data is 0.94. The correlation between simulated and observed adoption probabilities is also very high at 0.89. Turning to innovation effort, the correlation between model and data for R&D expenditures as a share of world output is 0.81. Finally, for licensing activity, the correlation between simulated and observed log-royalty payments is 0.69.

The first two correlations are particularly high because, even though we did not target the full transition path, we disciplined the BGP values. The strong fit for R&D effort and royalties further supports the model’s ability to reproduce the joint dynamics of innovation, adoption, and licensing flows.

It is important to note that the coefficient on the interaction term $\log(d^P - 1) \times \text{IPR}$ in Table 6 is also an untargeted moment. Although the calibration disciplined the coefficient on $\log(d^P - 1)$ directly, the interaction term was left free.

6.2 Baseline transition to the BGP (USA–China)

We begin by documenting how the calibrated USA–China economy moves from the initial year to its BGP with no additional shocks. The six panels in Figure 2 report the objects we use as references for the counterfactuals: bilateral royalty rates, innovation effort as a share of world output, log consumption for each country, and the relative technology position.

Along the baseline, bilateral royalty rates decline as new/renewed contracts are priced

³Estimates for the data are based on bilateral royalties between 2001–2020. Model coefficients are produced by simulating the Balanced Growth Path. The calibration adjusts κ^ϕ to match the coefficient on $\log(d^P - 1)$.

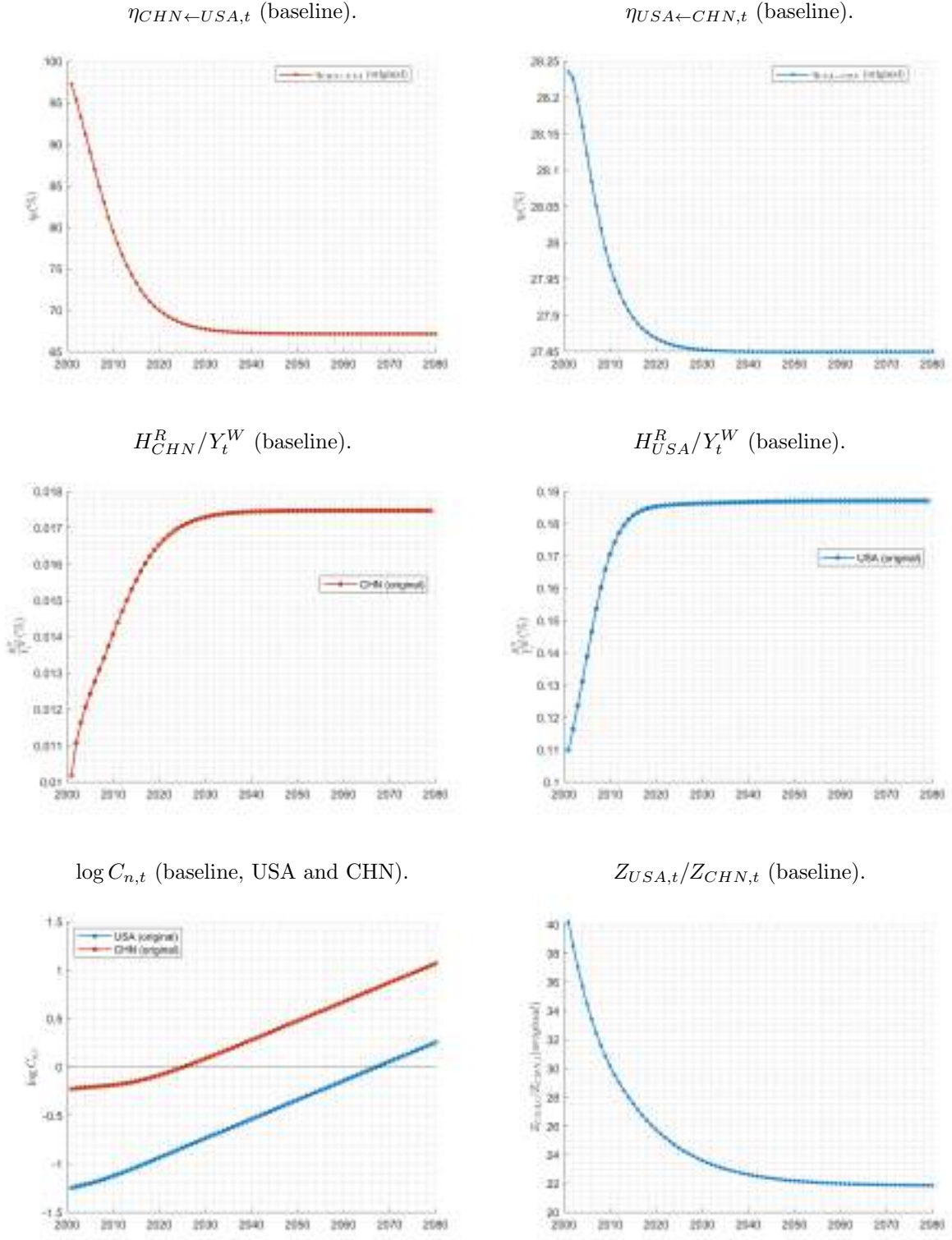


Figure 2: Baseline transition to the BGP: USA and China. Notes: No shocks added; parameters and wedges are from the calibration. These paths are the reference trajectories for the counterfactuals.

at lower rates. With ρ_{in} and $\phi(d_{in}^P)$ held fixed in the baseline, time variation in $\eta_{in,t}$ comes from the ratio $\Upsilon_{in,t}^{\text{Breach}}/\Upsilon_{in,t}$ in

$$\eta_{in,t} = \rho_{in} \left[1 + \Upsilon_{in,t}^{\text{Breach}} / \Upsilon_{in,t} \right].$$

By definition, $\Upsilon_{in,t}$ is the present value of the adopter's profit stream *along the compliant path*, i.e., profits $\pi_{in,\tau}$ weighted by survival $(1 - \phi(d_{in}^P))$ and discounted by $P_{i,\tau-1}/(R_{\tau-1}P_{i,\tau})$. Along the transition, $\pi_{in,\tau}$ rises with the state of the economy, so the discounted sum that defines $\Upsilon_{in,t}$ increases. In contrast, $\Upsilon_{in,t}^{\text{Breach}}$ is the continuation value that only materializes *after* a breach; with a constant hazard $\phi(d_{in}^P)$, this component is pushed further into the future and is discounted more heavily than the compliant flow. As the profit stream scales up over time, the compliant value $\Upsilon_{in,t}$ grows faster (in relative terms) than the breach continuation $\Upsilon_{in,t}^{\text{Breach}}$, so the ratio $\Upsilon_{in,t}^{\text{Breach}}/\Upsilon_{in,t}$ *falls*. Early contracts are therefore signed when $\Upsilon_{in,t}$ is relatively small and the ratio is large, yielding higher $\eta_{in,t}$; later contracts are written when $\Upsilon_{in,t}$ is larger and the ratio is smaller, yielding lower $\eta_{in,t}$ —even though ρ_{in} and $\phi(d_{in}^P)$ are unchanged.

On the R&D side, innovation effort $H_{n,t}^R/\bar{Y}_t$ rises along the transition and then settles at country-specific BGPs. The United States stabilizes at a higher $H_{n,t}^R/\bar{Y}_t$ than China, reflecting stronger steady-state incentives to innovate.

For consumption, $C_{n,t}$ grows smoothly over time; in logs, the path is close to linear, indicating convergence to a common long-run growth rate. Level differences across countries reflect initial conditions in technology and wealth as well as the gradual repricing of licensing transfers implied by $\eta_{in,t}$. Because repricing is spread over contract renewals, there are no large front-loaded swings in $C_{n,t}$ in the baseline.

Finally, the relative technology position $Z_{\text{USA},t}/Z_{\text{CHN},t}$ narrows during the transition and then stabilizes above one. The narrowing reflects faster R&D accumulation in China during catch-up and the diffusion of ideas, while the stabilization above one captures the higher stationary research intensity in the United States. Thus, the baseline features a smaller but persistent US lead by the time the economy reaches the balanced growth path.

These transitions have implications for welfare. Because consumption rises smoothly in both countries and large adjustments are not front-loaded, the discounted welfare ranking is driven by early-period level differences rather than by abrupt losses. They also speak to national-security considerations. The shrinking but positive technology gap implies persistent US leadership with tighter distance. If policymakers place weight on relative technological leadership, this narrowing can create a tension with purely consumption-based objectives.

6.3 Counterfactual Analysis

In this section, we use the calibrated model to conduct counterfactual analysis. We examine the effects of an increase in geopolitical distance between the United States and China, both in the short run and the long run, on innovation, growth, and welfare. We then analyze the optimal export control policy from the perspective of the United States. Specifically, we ask: under what conditions is it optimal for the United States to unilaterally restrict technology exports to geopolitical rivals? To address this question, we augment the government’s welfare function with an additional term that captures national security preferences.

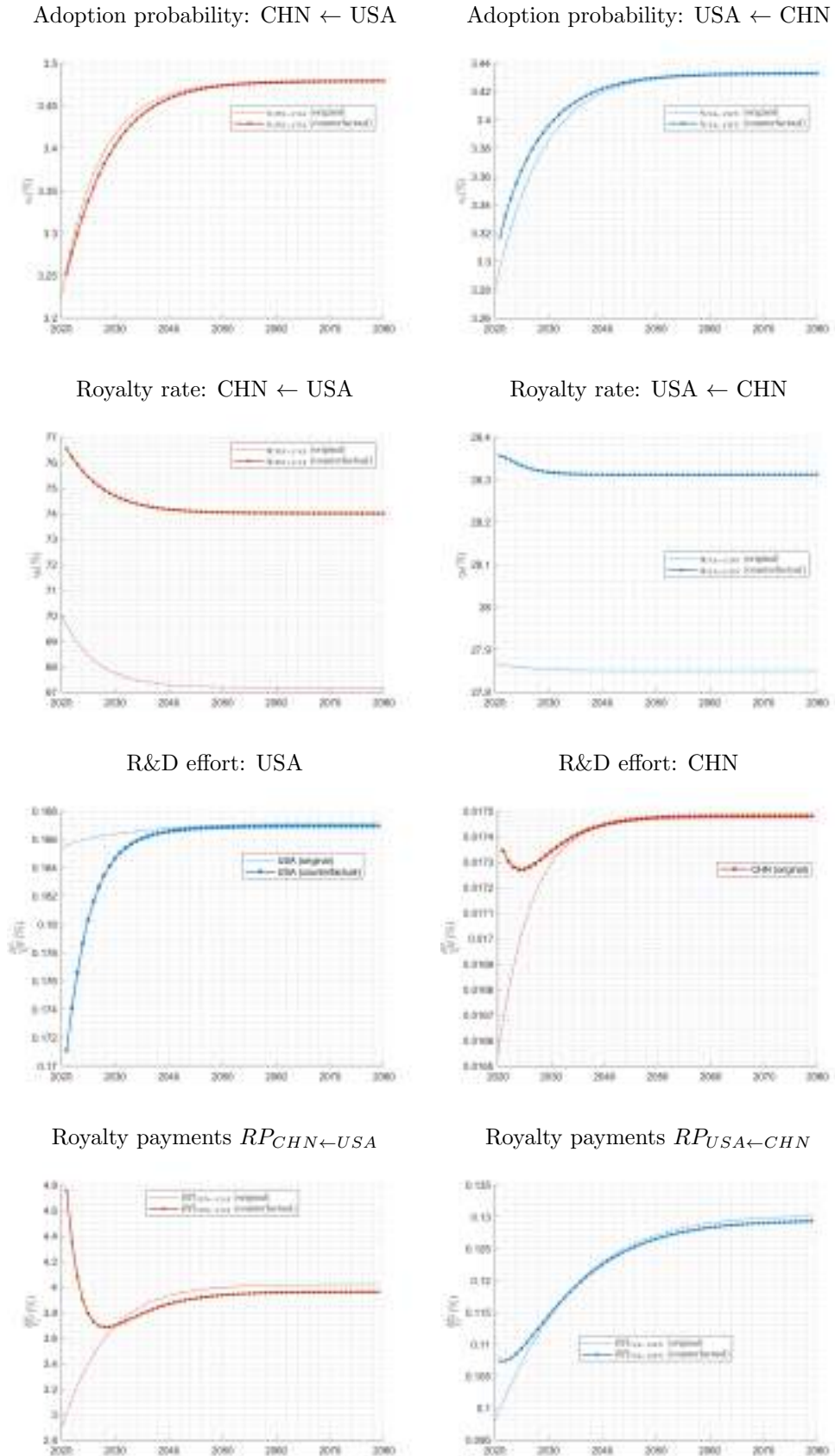
Bilateral US–China Fragmentation We now focus on the counterfactual where geopolitical distance between the United States and China rises permanently. Figures 3 plot the impulse responses of adoption probabilities and royalty rates. In each case, the dotted line shows the baseline transition from the observed state toward the original BGP without further shocks, while the solid line shows the new transition path when the US–China shock occurs in the first period. The relevant comparison is therefore between the two lines.

A key asymmetry emerges in adoption. In the baseline, both $\epsilon_{CHN \leftarrow USA}$ and $\epsilon_{USA \leftarrow CHN}$ rise smoothly as technology diffuses. After the shock, *US adoption of Chinese technologies* overshoots in the short run—firms front-load contracts under weaker enforcement, but legitimate adoption later declines and its long-run path falls below the baseline. By contrast, *China’s adoption of US technologies* does not overshoot: higher royalty fees and weaker contract enforcement make new adoption less profitable, so $\epsilon_{CHN \leftarrow USA}$ grows more slowly and stabilizes at a lower level. The royalty fee on China’s imports of US technology rises more sharply, from about 70 percent to nearly 77 percent, as US innovators demand higher compensation for risk. Initially, total royalty payments increase due to this rise in the fee, but as adoption falls and fewer technologies are transferred legitimately, total payments eventually decline below the baseline.

On the innovation margin, US R&D effort H_{USA}^R/Y^W continues to rise, but the increase is dampened compared to the baseline: in the first period after the shock, the US immediately reduces its R&D relative to the dotted path, and the gap persists. China’s R&D effort is flatter: it hardly responds on impact and then grows more slowly thereafter. The consequence is a decline in relative technological leadership: the ratio Z_{USA}/Z_{CHN} falls below the baseline, indicating that the US loses ground to China, whereas in the no-shock path it would have maintained a higher relative position.

The consumption paths highlight the asymmetric effects. In the baseline, both countries converge smoothly upward. With the shock, the United States initially records a small positive deviation from the baseline. China, by contrast, experiences an immediate

Figure 3: Impulse responses for adoption, royalty rates, R&D, and royalty payments following a permanent increase in US–China geopolitical distance. Dotted lines denote the baseline transition to the original BGP; solid lines denote the counterfactual path with the shock in the first period.



negative deviation, as weaker contract enforcement and higher breach risk make technology adoption costlier. These short-run effects stem from the different exposure of each country to the two main frictions in the model: the United States is primarily affected through the trade channel, while China is hit more strongly through the breach channel.

Over time, however, these forces reverse. The initial U.S. gain dissipates as lower royalty revenues and weaker foreign adoption reduce incentives to innovate. China’s consumption recovers partially, but its weaker IPR enforcement prevents sustained innovation-led growth. In the long run, both economies converge to lower consumption levels than in the baseline, but the welfare loss is substantially larger for China, consistent with its stronger dependence on foreign technologies. The short-run divergence thus evolves into a persistent asymmetry in both welfare and growth, as the decline in global licensing

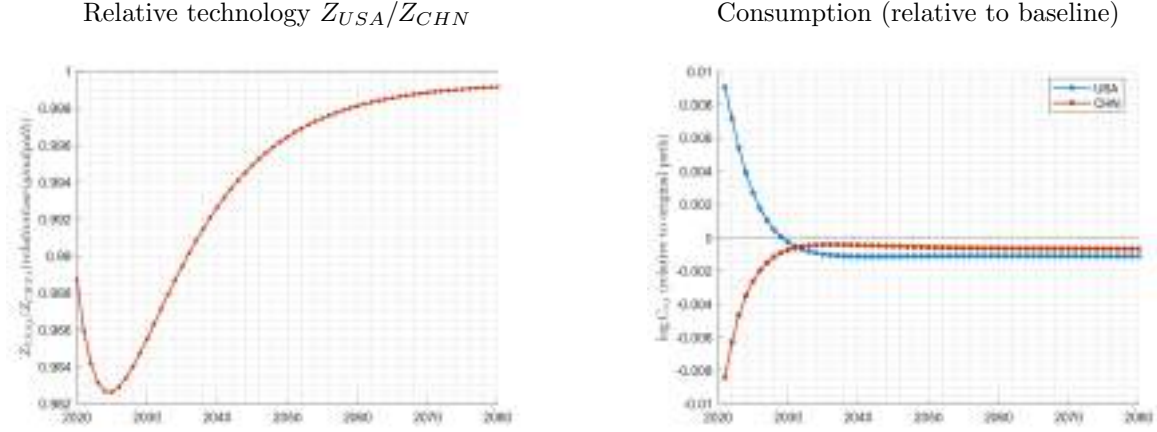


Figure 4: Welfare-relevant outcomes of a permanent increase in US–China geopolitical distance. Relative technology shows the erosion of US leadership, while consumption captures the asymmetric welfare costs for the US and China.

The US–China fragmentation experiment highlights the key mechanisms driving the model. An increase in $d_{USA,CHN}^P$ simultaneously raises trade costs and breach risk. Through the trade channel, both countries lose market access to one another, reducing the potential size of the licensing market. Through the breach channel, adopters in China initially over-adopt US technologies because contracts become less enforceable, while US innovators raise royalty rates to compensate for higher risk. Over time, as contracts are increasingly breached, legitimate adoption falls and royalty payments collapse.

In equilibrium, lower royalty revenues weaken US innovation incentives, leading to a decline in R&D effort relative to the baseline. China’s R&D remains flatter and less responsive, reflecting limited spillovers from foreign licensing. Consequently, relative technological leadership erodes over time: the ratio Z_{USA}/Z_{CHN} declines despite both countries remaining on positive growth paths. The long-run growth rate of global consumption, $g^{C,BGP}$, falls by about 0.006%, as shown in Table 7. This reduction captures the global efficiency costs of fragmentation through reduced innovation and weaker knowledge

diffusion.

Global Spillovers. The bilateral effects from the USA-China fragmentation propagate worldwide through the reallocation of trade and technology flows. As the United States and China reduce licensing with one another, third countries become relatively more attractive technology partners. Japan and Canada, both with strong IPR protection, benefit modestly from these spillovers: their welfare rises as they absorb displaced innovation rents. By contrast, Mexico, Korea, and the Rest of the World suffer welfare losses. Their dependence on US or Chinese technologies implies that fragmentation reduces access to the global knowledge pool, lowering adoption opportunities and dampening long-run growth. The Euro Area remains roughly neutral, as reduced access to China is offset by greater integration with the US and Japan.

In the extreme case in which US and China fully decouple, both in trade and technology, the bilateral patterns are amplified: the global growth rate declines sharply by 0.139%, the US suffers from lost market access, and China loses adoption opportunities, while Japan and Canada benefit modestly from displaced technology flows. Mexico again experiences the largest welfare and growth losses, consistent with its structural dependence on the US market.

Table 7: Welfare and Growth Effects of Geopolitical Fragmentation (consumption-equivalent changes, %)

Region	US-CHN Rivalry	US-CHN Decouple
USA	0.046	-0.193
CAN	0.054	-0.034
MEX	-0.321	-0.348
EUR	0.012	-0.027
CHN	-0.154	-0.192
JPN	0.363	0.464
KOR	-0.315	-0.181
ROW	-0.177	-0.220
$\% \Delta(g^{C,BGP})^4$	-0.006	-0.139

Notes: Each column corresponds to one counterfactual experiment. Positive values denote welfare or growth gains; negative values denote losses. Growth rates refer to changes in the BGP consumption growth rate.

These results point at a reallocation of trade and innovation activity toward economies that remain closely integrated with both blocs. When geopolitical distance increases only between the United States and China, the model produces two reinforcing mechanisms.

Trade Channel. In the trade block, higher political distance raises bilateral frictions between the two countries, reducing their trade shares. Since bilateral exports satisfy

$$X_{ij} = \frac{(d_{ij}^G)^{-\kappa_G} (d_{ij}^P)^{-\kappa_P} T_j}{\sum_m (d_{im}^G)^{-\kappa_G} (d_{im}^P)^{-\kappa_P} T_m} Y_i, \quad (40)$$

an increase in d_{UC}^P lowers X_{UC} and X_{CU} , compressing trade between the United States and China. Production and intermediate-goods demand then reallocate toward nearby and geopolitically aligned partners. Japan, remaining close to both blocs, absorbs a larger share of trade, while Mexico, a geographically distant partner from China and with a smaller technology base, gains little. The trade mechanism thus directs part of the global adjustment toward Japan.

Innovation Channel. The innovation block amplifies this pattern. R&D incentives depend on the value of innovation, so higher geopolitical distance reduces the enforceable share of royalties that US innovators receive from China, lowering the value of innovation in the United States and slowing Z_U . Japan's distance to both blocs is unchanged, so its royalty income and innovation incentives are preserved. In addition, the expansion of its trade share raises market size and further increases the return to R&D. Given Japan's high λ_J , its research effort rises, boosting Z_J and, through T_J , reinforcing its export capacity. Mexico, with low λ_M and limited domestic research, does not experience this amplification.

Interaction Between Trade and Innovation. As Z_J increases, the rise in T_J feeds back into the trade equation, further improving Japan's competitiveness. This feedback between trade and innovation magnifies Japan's relative gains. The United States loses royalties and market access, while Mexico, which is less innovative, suffers persistent declines in welfare. Fragmentation therefore reallocates global trade and innovation activity toward economies that combine high R&D productivity and geographically and geopolitical closeness.

6.4 Optimal Export Control Policy

Next, we examine under what conditions the US government would have an incentive to impose unilateral export controls on China when geopolitical distance increases. The objective is to understand how national security considerations can be incorporated into the welfare function to rationalize observed policy behavior.

Formally, we let the US choose a *unilateral* export-control intensity $\xi \in [0, 1]$ on the

USA–China technology link that impacts technology adoption:

$$\epsilon_{in,t} = (1 - \chi_{in})\bar{\epsilon}_{in} \left(\frac{H_{in,t}^A}{\bar{Y}_t} \right)^{\beta^A} \quad \beta^A \in (0, 1)$$

Because private contracts do not internalize national-security externalities and our instrument set is restricted, the allocation we study is not first best. We therefore consider a *constrained* policy problem. We begin with a government that maximizes lifetime household consumption and evaluate unilateral technology export controls as bilateral instruments that can be targeted to specific destinations. The policy is chosen taking the private environment (pricing of licensing risk, adoption technology, and market-size wedges) as given; hence all policy conclusions are *constrained-optimal* within this instrument class.

Standard consumption-based welfare function In the counterfactual analysis presented above, welfare gains were computed under a standard consumption-based welfare function, where the government values only lifetime household consumption. Under this benchmark, an increase in geopolitical distance between the United States and China leads to a small *increase* in US welfare, while global growth declines only marginally. Hence, if the government only cares about consumption, there is no rationale for imposing export controls: the optimal level of the export restriction is zero. In other words, fragmentation by itself makes the United States slightly better off, and additional restrictions would only reduce efficiency and long-run growth.

Figure 5 illustrates this result. The figure plots the consumption-equivalent welfare effects for each major economy as a function of χ , the bilateral wedge that captures the intensity of US export controls on China. When $\chi = 0$, technology flows freely, and higher values represent tighter restrictions on US technology exports. The figure shows that US welfare declines monotonically with χ , implying that, under a pure consumption-based welfare criterion, the optimal policy is $\chi = 0$. By contrast, other countries, such as Japan and Korea, benefit from higher χ as tighter US export controls divert technology diffusion toward them.

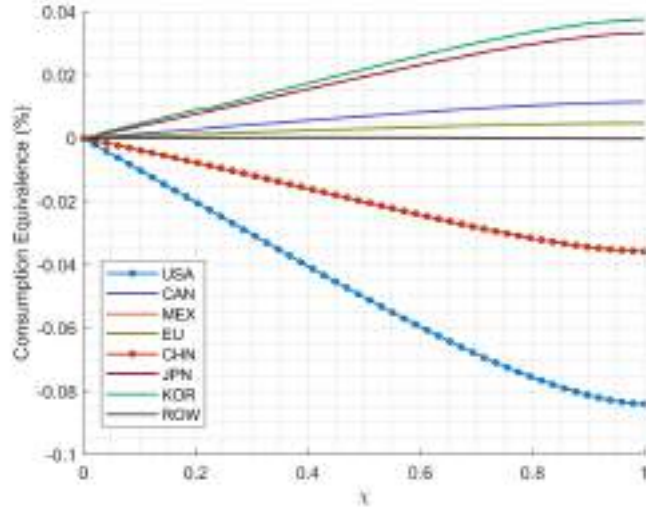


Figure 5: Consumption-equivalent welfare effects of export controls (χ) if the government values only consumption. Higher χ denotes tighter US export restrictions on China.

Augmented Welfare Function. We have found empirically that geopolitical distance is associated with larger declines in cross-border *technology* flows than in goods trade, particularly where IPR is weak. This pattern can be rationalized by firms' contracting behavior even before any policy is introduced. When political distance rises, the perceived probability of breach $\phi(d^P, \text{IPR})$ increases; licensors renegotiate higher royalty terms η to price this risk, but pricing cannot fully insure two quantity margins: (i) *new* legitimate licenses (fewer are signed), and (ii) *surviving* compliant contracts (fewer remain in force). In parallel, the market-size channel compresses bilateral trade shares s_{ij} , shrinking the effective licensing market. The result is that, despite $\eta \uparrow$, enforceable surplus declines and recorded royalty payments and diffusion fall—precisely the asymmetry the data reveal.

In the benchmark where the government cares only about consumption, these firm-level adjustments are sufficient to explain a small *net* US welfare gain when U.S.–China geopolitical distance rises. Intuitively, there is a short-run, front-loaded boost to royalty receipts as rates increase before quantities fully adjust, and a mild reallocation toward safer, strong-IPR partners that partially offsets the bilateral contraction with China. Discounted over time, these effects slightly outweigh the longer-run drags from smaller markets and fewer compliant contracts, yielding a modest positive welfare effect for the US under $\theta = 0$. Because export controls would further reduce consumption (foregone royalties and market size) without delivering additional benefits in this benchmark, there is *no* motive to intervene.

To reconcile the model with the observed US policy of imposing unilateral export restrictions on China, we augment the government's welfare function to include a *national security term*. This term captures the strategic objective of maintaining technological leadership over geopolitical rivals with weak intellectual property rights enforcement.

The government now maximizes

$$W_{US}^A = \sum_{t=0}^{\infty} \beta^t \left[(1 - \gamma_{US,CHN}) \cdot u(C_{US,t}) + \gamma_{US,CHN} \cdot g\left(\frac{Z_{US,t}}{Z_{US,t} + Z_{CHN,t}}\right) \right], \quad (41)$$

where $g(\cdot)$ is an increasing function of the bilateral technology gap, $\gamma_{US,CHN}$ increases with geopolitical distance and the weakness of China's IPR regime, and $\theta > 0$ measures the weight of the national security motive in the government's welfare. In this formulation, a decline in the relative technology ratio Z_{US}/Z_{CHN} reduces welfare even if consumption temporarily increases. The government may thus find it optimal to impose export controls that slow down China's technological catch-up, sacrificing some consumption to preserve strategic leadership.

With an augmented objective, even if firms already reprice risk, the government may still restrict technology diffusion to slow a rival's catch-up, provided the (weighted) leadership gains exceed the consumption costs. In this case, the evidence would be consistent with firms' partial insurance and quantity contraction; the small benchmark gains explain why there is no intervention under consumption-only preferences; and the policy motive appears only when leadership enters the welfare calculus.

We study the US choice of a unilateral export-control intensity $\chi \in [0, 1]$ on the US-China technology channel when there is a rivalry shock to $d_{USA,CHN}^P$ for three cases: (i) no retaliation, (ii) certainty of retaliation by China, and (iii) retaliation by China with a time-varying probability. For each χ we solve the perfect-foresight transition and evaluate US consumption-equivalent welfare.

In the first case, without retaliation, if the national-security weight exceeds roughly one-third ($\gamma > 0.30$), the optimal US control is a full ban ($\chi = 1$); for lower weights ($\gamma < 0.30$), the optimum is zero ($\chi = 0$). In the second case of certain retaliation, that is, if China matches the US control one-for-one, the optimal unilateral US control is $\chi = 0$ for all γ . The corner solution in these cases is driven by a monotone welfare loss from tighter controls that exhibits little curvature, so marginal costs do not cross marginal benefits at an interior point; adding a security motive simply flips the monotonicity (in the no-retaliation case) and moves the maximizer to the opposite boundary. In summary, absent retaliation risk, a sufficiently high weight on national security rationalizes a full ban; once retaliation is certain, expected losses dominate and restraint is always optimal.

In the third case, we let the probability of Chinese retaliation rise with the US choice of χ . Specifically, we set $\chi^{CHN} = \chi$ with probability $p(\chi) \in [0, 1]$ where $p'(\chi) > 0$, and

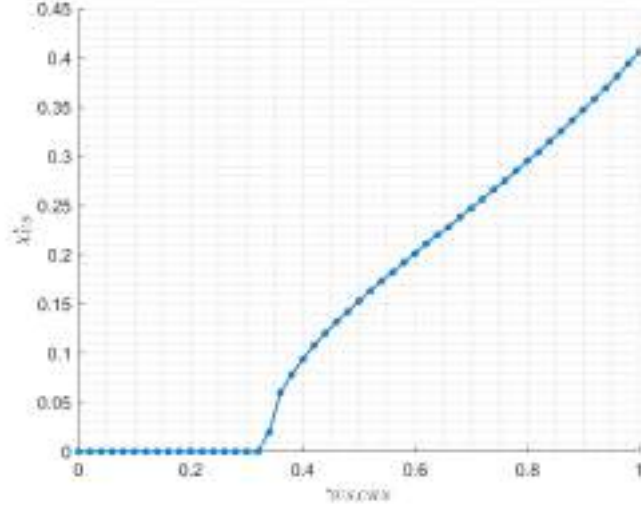


Figure 6: Optimal US export-control intensity χ_{USA}^* as a function of the national-security weight $\gamma_{USA,CHN}$ under retaliation probability $p(\chi) = \chi^2$ and matching response $g(\chi) = \chi$.

we assume $p(\chi) = \chi^2$. The welfare function becomes

$$\begin{aligned} \mathcal{W}_{US}(\chi, \gamma_{US,CHN}) = & (1 - p(\chi)) [CE_{US}^{NR}(\chi) + \gamma_{US,CHN} \Lambda_{US}^{NR}(\chi)] \\ & + p(\chi) [CE_{US}^R(\chi) + \gamma_{US,CHN} \Lambda_{US}^R(\chi)]. \end{aligned}$$

and we choose $\chi^*(\gamma) \in \arg \max_{\chi \in [0,1]} \mathcal{W}_{US}(\chi, \gamma)$. Because $p(\chi)$ is increasing, small χ delivers leadership gains at low risk, whereas large χ shifts the objective toward the retaliation state; this curvature generates an interior optimum.

Figure 6 reports the optimal US export control as a function of the weight on national security, γ . For security weights at or below roughly one-third, the optimal export controls are zero. Beyond this threshold, the solution becomes interior and increases approximately linearly with γ , reaching about forty percent when the weight is set to one. Intuitively, placing more weight on national security raises the marginal benefit of restricting idea flows, but the rising probability of retaliation makes large controls increasingly costly, so the optimum moves inward rather than toward a full ban as the security weight grows.

These findings rationalize the use of unilateral export controls in environments in which policy design is informed not only by considerations of efficiency and global knowledge diffusion, but also by national security and technological self-reliance (Airaudo et al., 2025). In line with this perspective, Chatterji and Murray (2025) emphasize that geo-economic forces are reshaping the innovation landscape, impacting the trade-off between openness and strategic control.

7 Final Remarks

This paper develops a quantitative framework linking geopolitical rivalry, institutional quality, and international technology transfer. We document empirically that technology flows are far more sensitive than goods trade to geopolitical distance, especially where intellectual property rights are weak. We then build a model in which geopolitical distance raises breach risk in licensing contracts, weakening the link between innovation and diffusion. The model reproduces the core empirical regularities and provides a unified account of how fragmentation shapes trade, innovation, and welfare.

Our quantitative analysis delivers three main insights. First, fragmentation along geopolitical lines entails welfare costs. Second, these costs are uneven: economies with strong IPR regimes, such as Japan and Canada, can partially offset losses through reallocation, while weaker-IPR economies experience deep and persistent declines in adoption and growth. Third, once governments value relative technological leadership, unilateral export controls may become welfare-improving despite efficiency losses. This mechanism offers a formal rationale for the rise of technology restrictions as a tool of national security policy.

The results highlight a broader message: when innovation and diffusion are globally connected, geopolitical shocks propagate not only through trade but also through the incentives to create and share knowledge. Policies that appear protectionist in static terms may thus reflect intertemporal trade-offs between consumption and strategic advantage. Quantifying these trade-offs clarifies the conditions under which efficiency-reducing interventions, such as export controls, can improve welfare once security considerations are taken into account.

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A Appendix

A.1 Data

Data Sources The empirical analysis combines multiple international datasets, harmonized at the bilateral-year level. The dataset contains 42 countries and a category called ROW (Rest of the World). The ROW category aggregates the following variables for all other countries in the dataset. The 41 countries were identified from the World Input Output Database (WIOD). Vietnam was added later. The key variables and their sources are:

- **Trade Flows:** Annual bilateral trade in current thousand USD, from the BACI database maintained by CEPII. BACI reconciles export and import declarations in UN Comtrade to provide consistent and symmetric trade flows. Here, the bilateral *trade_flow.baci* ranges from 2000 to 2021. The initially unbalanced dataset was subsequently balanced. Finally, all the NAs were replaced by 0.
- **Royalties:** Charges for the use of intellectual property (millions USD), from OECD's Balanced Trade in Services or BaTIS. These cover payments between residents and non-residents for the authorized use of intellectual property, including patents, trademarks, and industrial processes. Here, the bilateral balanced export data was used from the year 2005 till 2021.
- **Geopolitical Distance:** Bilateral ideal-point distance (IPD) based on United Nations General Assembly roll-call voting, following the methodology of Bailey, Strezhnev, and Voeten (2017). The scores are derived from a dynamic ordinal item-response model and reflect long-run foreign policy alignment. Here, *Idealpointall* is used, which is based on all votes, including votes on paragraphs and amendments. The *Idealpointall* measure contains the ideal-point distance for each country. The ideal-point for the country pair is subtracted, and its absolute value is taken. Then, the log of the difference is used. Here, the IPD data ranges from the year 2000 till 2021.

To ensure robustness, multiple variations of the ideal-points were used in regression models. These include: *idealpointfp* from Bailey, Strezhnev, and Voeten (2017), which calculates the ideal-point based on the final votes at the United Nations; *ipd_all_full* from Airaud et al. (2025), which estimates IPD using the full sample of UN votes; *ipd_econ_full* from Airaud et al. (2025), which estimates IPD using the subset of only economic votes; and finally, *ipd_all_short*, which estimates IPD from the sample of all UN votes after 1991. The regression results are consistent across all the IPD measures, ensuring robustness.

- **IPR Protection:** Protection of Intellectual Property Rights (IPR) (0–10 scale) is a component of the International Property Rights Index, published annually by the Property Rights Alliance. The data captures citizens’ perspectives on the protection of intellectual property in their country. Here, the scale was normalized by dividing it by 10. Here, the IPR Protection data ranges from the year 2007 till 2021.

Similar to geopolitical distance, there were multiple variations of protection of intellectual property rights that were used in the regression models to ensure robustness of the results. These include: *International Property Rights Index*; *Intellectual Property Rights Subindex*, which includes protection of intellectual property rights as one of its factors. *Patent Protection* was used as one of the variations; however, the index had more NAs than all other indices. Finally, *Protection of Intellectual Property Rights* was chosen as in the final regression model it was directly related to the aim of the paper. The regression results are consistent across all IPR measures, ensuring robustness.

- **Geographic Distance, Common Language, Contiguity, and Trade Agreements:** Data sourced from CEPII’s Gravity dataset. Geographic distance is measured as the great-circle distance between capital cities, with log distance used in the regression. Contiguity indicates whether countries share a land border. Trade agreement participation covers common membership in FTAs or the WTO. Common language indicates whether the countries share a common primary or official language. Like trade flow data above, the above variables ranges from 2000 to 2021.

Table 8: Descriptive Statistics of Key Variables

	Mean	SD	Min	25%	Median	75%	Max	Count
IPR Index	0.64	0.16	0.24	0.51	0.62	0.79	0.93	26,082
Log Geographical Distance	-1.05	1.54	-14.85	-1.97	-0.79	0.21	1.47	39,564
Royalties (Mill. USD)	133.82	881.21	0.00	0.00	1.35	21.31	56376.05	39,732
Trade Flow (thous. USD)	6,147,378	24,400,000	0.00	98,306.91	634,319.6	3,219,325	775,000,000	39,732

Identifying Country-Pairs Driving Positive Geopolitical Impact on Royalties

A natural concern is whether the positive coefficient on geopolitical distance in our baseline regressions is driven by tax havens that attract royalty payments for fiscal rather than technological reasons. To address this, we re-estimate the specification excluding common tax havens. Consistent with the idea that profit-shifting inflates our baseline results, the coefficient on geopolitical distance falls markedly in magnitude, although it remains positive and statistically significant. This suggests that part of the raw positive relationship between geopolitical distance and royalty flows is explained by the disproportionate role of jurisdictions such as Ireland, the Netherlands, and Switzerland, which

Table 9: List of Countries

ISO 3 Code	Country Name
AUS	Australia
AUT	Austria
BEL	Belgium
BGR	Bulgaria
BRA	Brazil
CAN	Canada
CHE	Switzerland
CHN	China
CYP	Cyprus
CZE	Czech Republic
DEU	Germany
DNK	Denmark
ESP	Spain
EST	Estonia
FIN	Finland
FRA	France
GBR	Great Britain
GRC	Greece
HRV	Croatia
HUN	Hungary
IDN	Indonesia
IND	India
IRL	Ireland
ITA	Italy
JPN	Japan
KOR	South Korea
LTU	Lithuania
LUX	Luxembourg
LVA	Latvia
MEX	Mexico
MLT	Malta
NLD	Netherlands
NOR	Norway
POL	Poland
PRT	Portugal
ROW	Rest of the World
RUS	Russian Federation
SVK	Slovakia
SVN	Slovenia
SWE	Sweden
TUR	Turkey
USA	United States of America
VNM	Vietnam

serve as major hubs for royalty routing despite their geopolitical distance from the United States.

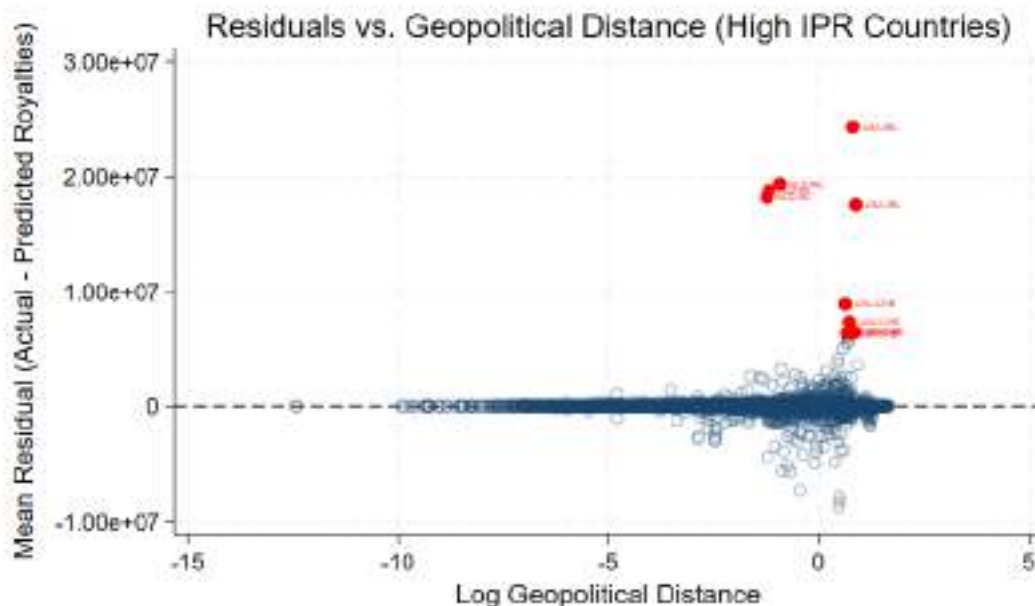


Figure 7: Residuals vs. Geopolitical Distance for High-IPR Country-Pairs

At the same time, when we examine residuals from this restricted regression, the largest positive outliers correspond to flows between highly innovative economies, in particular the United States and the European Union, and the United States and Japan. In these cases, royalty payments are systematically underpredicted by geopolitical distance alone. This pattern highlights that, once profit-shifting destinations are excluded, the positive association between distance and royalties is partly capturing the fact that technologically advanced economies engage in disproportionately high levels of licensing with one another, even across large geopolitical divides. In other words, geopolitical distance reduces the likelihood of licensing in weaker institutional environments, but among advanced economies with strong IPR protection, innovation intensity dominates, sustaining large royalty flows that are not fully explained by our baseline measure of distance. Figure 8 visualizes the residuals from our royalty regression without the interaction term. The scatter plot highlights country-pairs with the largest positive residuals—cases where observed royalty flows substantially exceed the values predicted based on geopolitical distance and other controls. Notably, pairs such as USA–Ireland, Netherlands–Ireland, and USA–Switzerland stand out prominently. These pairs register exceptionally high residuals despite varying levels of geopolitical distance, suggesting that other factors, such as favorable institutional environments for intellectual property and corporate taxation, may be at play.

Overall, these results suggest that the initial positive coefficient on geopolitical distance in the absence of IPR controls is partly driven by a narrow set of country-pairs with

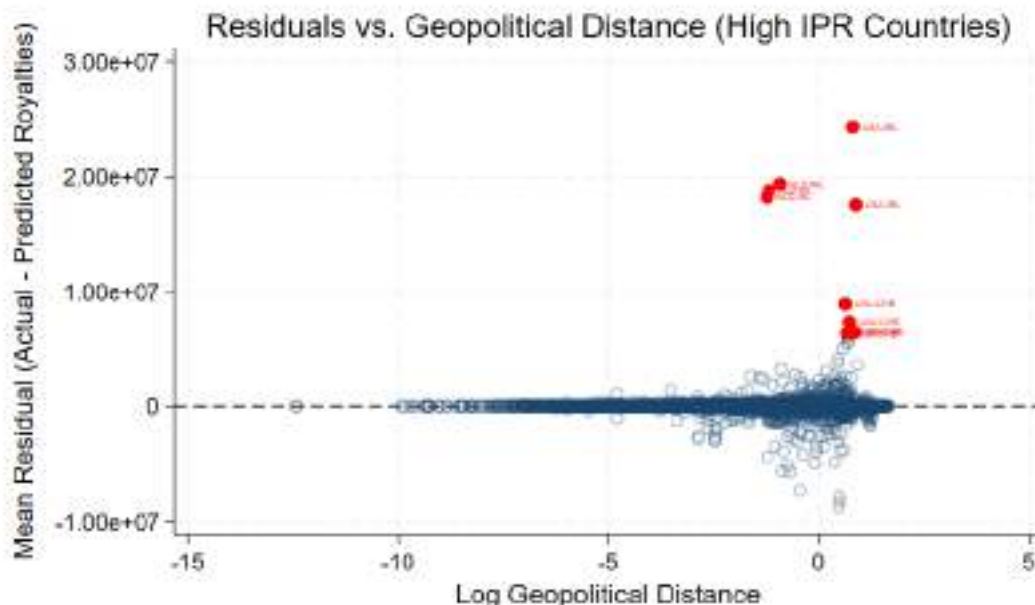


Figure 8: Residuals vs. Geopolitical Distance for High-IPR Country-Pairs

exceptional institutional or fiscal characteristics. This finding reinforces the importance of incorporating IPR measures into the empirical specification to accurately isolate the true effect of geopolitical distance on cross-border technology transfers.

A Subsample Analysis: Before and After 2017

To assess whether the effects of geopolitical distance and IPR protection have changed over time, we split the sample into two periods: 2007–2016 and 2017 onward. Tables 10 and 11 report the results.

Here are the main takeaways:

- **Trade flows:** The negative effect of geopolitical distance on merchandise trade is present in both periods, but it becomes larger in magnitude after 2017 (-0.043 without IPR interaction, compared to -0.012 before 2017). This suggests that political misalignment has become more consequential for goods trade in recent years.
- **Royalties without IPR interaction:** Before 2017, geopolitical distance shows a positive correlation with royalties (0.112), reflecting that many distant pairs involved high-income, strong-IPR importers. After 2017, this coefficient remains positive (0.067) but smaller, indicating some erosion of this compensating pattern.
- **Royalties with IPR interaction:** Once the interaction is included, the coefficient on geopolitical distance becomes strongly negative in both periods (-0.438

before 2017, -0.534 after 2017), and the interaction term is large and positive in both (0.789 vs. 0.814). This highlights that the mitigating role of IPR has been consistently strong, though the baseline geopolitical penalty deepened after 2017.

- **Interpretation:** The stronger geopolitical penalties after 2017 likely reflect the escalation of global tensions (US–China technology rivalry, Russia’s divergence, expanded use of export controls) that directly affected both goods and technology flows. The stability of the IPR interaction term indicates that robust institutions continue to buffer these frictions, but the baseline effect of distance has intensified.

Overall, the subsample analysis confirms the main finding: royalties are more vulnerable than trade to geopolitical distance, but strong IPR protection significantly dampens this effect. What changes after 2017 is the magnitude: geopolitical distance becomes a more binding constraint on both trade and technology, consistent with a more fragmented global environment.

Table 10: Impact of Geopolitical Distance and IPR on Trade and Royalties (PPML), 2007–2016

	No IPR Interaction		With IPR Interaction	
	Trade	Royalties	Trade	Royalties
FTA	0.499*** (0.033)	0.210*** (0.064)	0.497*** (0.033)	0.294*** (0.063)
Log Distance	-0.606*** (0.013)	-0.323*** (0.029)	-0.608*** (0.013)	-0.311*** (0.030)
Contiguity	0.556*** (0.032)	-0.112 (0.063)	0.563*** (0.033)	-0.061 (0.064)
Common language	0.076* (0.035)	0.098 (0.058)	0.077* (0.035)	0.042 (0.058)
Log Geopolitical Distance	-0.012 (0.007)	0.112*** (0.018)	-0.073*** (0.020)	-0.438*** (0.053)
Geo $\times$ IPR			0.103*** (0.031)	0.789*** (0.078)
Observations	17,052	17,052	17,052	17,052

A.1 Stationary system

The trick is that are two layers of normalization: normalize by $W_{M,t}$ for static block and by $T_{M,t}^{\frac{1}{\sigma-1}}$ for dynamic block.

Resource constraints:

$$\hat{C}_{n,t} = \hat{Y}_{n,t} - \hat{H}_{n,t}^R - \hat{H}_{n,t}^A \quad (42)$$

where $\hat{X}_{n,t} \equiv \frac{X_{n,t}}{T_{M,t}^{\frac{1}{\sigma-1}}}$.

Table 11: Impact of Geopolitical Distance and IPR on Trade and Royalties (PPML), 2017 onward

	No IPR Interaction		With IPR Interaction	
	Trade	Royalties	Trade	Royalties
FTA	0.408*** (0.050)	-0.077 (0.077)	0.399*** (0.050)	0.003 (0.074)
Log Distance	-0.582*** (0.019)	-0.355*** (0.034)	-0.586*** (0.019)	-0.342*** (0.034)
Contiguity	0.551*** (0.053)	-0.180 (0.120)	0.561*** (0.053)	-0.160 (0.121)
Common language	0.099 (0.057)	0.118 (0.104)	0.096 (0.057)	0.085 (0.103)
Log Geopolitical Distance	-0.043*** (0.012)	0.067* (0.026)	-0.242*** (0.046)	-0.534*** (0.089)
Geo $\times$ IPR			0.316*** (0.066)	0.814*** (0.132)
Observations	7,224	9,030	7,224	9,030

Price indices:

$$\hat{P}_{n,t}^{1-\sigma} = \sum_{i=1}^M \Omega_{it}^{\sigma-1} \hat{T}_{i,t} (\bar{m} \hat{\omega}_{i,t} d_{ni} (1 + \tau_{ni,t}))^{1-\sigma}$$

where $\hat{X}_{it} \equiv \frac{W_{i,t}}{W_{M,t}}$, $\hat{T}_{it} \equiv \frac{T_{i,t}}{T_{M,t}}$ and $\hat{P}_{n,t} \equiv \frac{P_{i,t} T_M^{\frac{1}{\sigma-1}}}{W_{M,t}}$.

Trade shares (This is stationary without normalization):

$$s_{in,t} = \frac{\Omega_{nt}^{\sigma-1} \hat{T}_{n,t} (\bar{m} \hat{\omega}_{n,t} d_{in} (1 + \tau_{in,t}))^{1-\sigma}}{\hat{P}_{i,t}^{1-\sigma}}, \quad (43)$$

We stationarize the value functions by rewriting

$$\hat{Q}_{n,t} \equiv \frac{T_{n,t} Q_{n,t}}{W_{M,t}}$$

where $Q = V, V^{Innov}, V^{Adopt}, V^{Breach}, J^{Innov}$ and J^{Adopt} .

And the value of innovation is:

$$\hat{V}_{n,t} \equiv \sum_{i=1}^M \hat{j}_{in,t}^{innov} \frac{\hat{T}_{n,t}}{\hat{T}_{i,t}} \quad (44)$$

Profits of all firms:

$$\hat{\Pi}_{n,t} \equiv \frac{\Pi_{n,t}}{W_{M,t}} = \bar{m} \hat{\omega}_{n,t} L_n \quad (45)$$

The value of contract breach:

$$\hat{V}_{in,t}^{Breach} = \bar{m}\hat{\omega}_{i,t}L_i + \frac{\hat{V}_{in,t+1}^{Breach}}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \quad (46)$$

where $g_{M,t} \equiv \frac{T_{M,t+1}}{T_{M,t}} - 1$, and $g_{T,i,t} \equiv \frac{\hat{T}_{i,t+1}}{\hat{T}_{i,t}}(1 + g_{M,t}) - 1$.

The value of adopted innovation to inventor:

$$\hat{V}_{in,t}^{Innov} = \eta_{in}\bar{m}\hat{\omega}_{i,t}L_i + (1 - \phi(d_{in}^P)) \frac{\hat{V}_{in,t+1}^{Innov}}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \quad (47)$$

The value of adopted innovation to adopter:

$$\hat{V}_{in,t}^{Adopt} = (1 - \eta_{in})\bar{m}\hat{\omega}_{i,t}L_i + \frac{(1 - \phi(d_{in}^P))\hat{V}_{in,t+1}^{Adopt} + \phi(d_{in}^P)\hat{V}_{in,t+1}^{Breach}}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \quad (48)$$

The value of unadopted innovation to inventor:

$$\hat{J}_{in,t}^{Innov} = \frac{1}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \left[\epsilon_{in,t} \hat{V}_{in,t+1}^{Innov} + (1 - \epsilon_{in,t}) \hat{J}_{in,t+1}^{Innov} \right] \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \quad (49)$$

The value of unadopted innovation to adopter:

$$\hat{J}_{in,t}^{Adopt} = \frac{1}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \left[(1 - \beta_a) \epsilon_{in,t} \hat{V}_{in,t+1}^{Adopt} + (1 - \epsilon_{in,t} + \beta_a \epsilon_{in,t}) \hat{J}_{in,t+1}^{Adopt} \right] \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \quad (50)$$

A.2 Setup of skipping royalty payments instead of complete contract breach

A.2.1 Value Functions and Licensing agreements

The value of an innovation from n which is successfully adopted by country i is

$$V_{in,t}^{innov} = (1 - \phi(d_{in}^P)) \eta_{in,t} \pi_{in,t} + \frac{1}{R_t} \frac{P_{i,t}}{P_{i,t+1}} V_{in,t+1}^{inno} \quad (51)$$

where $\eta_{in,t}$ is the profit sharing according to the licensing agreement and $\phi(d_{in,t}^P)$ is the probability that the adopter **skips** the royalty payment. This is an increasing function of the geopolitical distance. In case of the breach of contract, the value attributed to innovator is 0.

The value of an innovation from country n which has not been adopted in country i

is

$$J_{in,t}^{innov} = \frac{1}{R_t} \frac{P_{i,t}}{P_{i,t+1}} [\epsilon_{in,t} V_{in,t+1}^{innov} + (1 - \epsilon_{in,t}) J_{in,t+1}^{innov}] \quad (52)$$

The value of successful adopter is

$$V_{in,t}^{adopt} = [(1 - \phi(d_{in}^P))(1 - \eta_{in,t}) + \phi(d_{in}^P)] \pi_{in,t} + \frac{1}{R_t} \frac{P_{i,t}}{P_{i,t+1}} V_{in,t+1}^{adopt} \quad (53)$$

The value of to-be-adopted innovation is

$$J_{in,t}^{adopt} = -P_{it} h_{in,t}^a + \frac{1}{R_t} \frac{P_{i,t}}{P_{i,t+1}} [\epsilon_{in,t} V_{in,t+1}^{adopt} + (1 - \epsilon_{in,t}) J_{in,t+1}^{adopt}] \quad (54)$$

The total value of an innovation from country n

$$V_{n,t} = \sum_{i=1}^N J_{in,t}^{innov} \quad (55)$$

A.2.2 Royalty Fee

The total surplus value of adoption equals to stream of profits created

$$W_{in,t} = \pi_{in,t} + \frac{1}{R_t} \frac{P_{i,t}}{P_{i,t+1}} W_{in,t+1} \quad (56)$$

However, with the possibility of a breach of contract, innovator and adopter negotiate on η_{in} to maximize

$$\left[V_{in,t}^{innov} \right]^{\rho_{in}} \left[V_{in,t}^{adopt} \right]^{1-\rho_{in}} \quad (57)$$

Nash bargaining implies that⁵:

$$\eta_{in} = \frac{\rho_{in}}{1 - \phi(d_{in}^P)} \quad (58)$$

B Technology Adoption

Let A_t denote the stock of technologies adopted at time t . These technologies come from two sources: new technologies that arrive between periods $t - 1$ and t , and previously legitimate technologies that have not yet been imitated. We define A_t^L as the stock of legitimate technologies at time t that generate royalty revenue.

⁵If we assume adopter breaches the contract (terminates the payment, instead of skipping one), η_{in} would be smaller than $\frac{\rho_{in}}{1-\phi}$ because $V_{in,t}^{inno} \leq W_{in,t}$ and $V_{in,t}^{adopt} \leq W_{in,t}$. Hence, it would induce even less incentives to adopt.

The dynamics of technology adoption and imitation are governed by the following parameters:

- $\phi_t \in [0, 1]$: The probability that a legitimate technology is imitated after one period
- η_t : The royalty fee applied to legitimate technologies
- π_t : The profit generated by each technology
- T_t : The total number of available technologies in the market

B.1 Evolution of Legitimate Technologies

The stock of legitimate technologies evolves according to:

$$A_t^L = (A_t - A_{t-1}) + (1 - \phi_t)A_{t-1}^L \quad (59)$$

This equation captures two components:

- $(A_t - A_{t-1})$: Newly adopted technologies between periods $t - 1$ and t
- $(1 - \phi_t)A_{t-1}^L$: Previously legitimate technologies that remain unimitated

B.2 Royalty Revenue Generation

The total royalty revenue generated at time t is given by:

$$RP_t = \eta_t \frac{A_t - A_{t-1}}{T_t} \pi_t + \eta_t (1 - \phi_t) A_{t-1}^L / T_t \quad (60)$$

This expression consists of two terms:

- $\eta_t \frac{A_t - A_{t-1}}{T_t} \pi_t$: Royalty revenue from newly adopted technologies, where $\frac{A_t - A_{t-1}}{T_t}$ represents the fraction of new technologies relative to all available ones
- $\eta_t (1 - \phi_t) A_{t-1}^L / T_t$: Royalty revenue from previously legitimate technologies that remain protected from imitation

B.3 Balanced Growth Path Analysis with Explicit Treatment of Past Technologies

On a balanced growth path (BGP), the technology stock grows at a constant rate g_A , defined as:

$$g_A = \frac{A_t - A_{t-1}}{A_{t-1}} \quad (61)$$

This implies:

$$A_t = (1 + g_A)A_{t-1} \quad (62)$$

$$A_{t-1} = \frac{A_t}{1 + g_A} \quad (63)$$

For any time period $t - j$:

$$A_{t-j} = \frac{A_t}{(1 + g_A)^j} \quad (64)$$

Additionally, the ratio of adopted technologies to total available technologies is constant:

$$\frac{A_t}{T_t} = \alpha \quad (65)$$

Therefore:

$$T_t = \frac{A_t}{\alpha} \quad (66)$$

$$T_{t-j} = \frac{A_{t-j}}{\alpha} = \frac{A_t}{\alpha(1 + g_A)^j} = \frac{T_t}{(1 + g_A)^j} \quad (67)$$

B.3.1 Explicit Derivation of Legitimate Technologies

The stock of legitimate technologies at time t consists of technologies from all past periods that have not been imitated. For a technology introduced in period $t - j$, the probability it remains legitimate at time t is $(1 - \phi)^j$.

The flow of new technologies in period $t - j$ is:

$$A_{t-j} - A_{t-j-1} = g_A A_{t-j-1} = \frac{g_A A_t}{(1 + g_A)^{j+1}} \quad (68)$$

Therefore, the stock of legitimate technologies at time t is the sum of all past tech-

nology flows, each adjusted by its probability of remaining legitimate:

$$A_t^L = (A_t - A_{t-1}) + (1 - \phi)(A_{t-1} - A_{t-2}) + (1 - \phi)^2(A_{t-2} - A_{t-3}) + \dots \quad (69)$$

$$= \sum_{j=0}^{\infty} (1 - \phi)^j (A_{t-j} - A_{t-j-1}) \quad (70)$$

$$= \sum_{j=0}^{\infty} (1 - \phi)^j \frac{g_A A_t}{(1 + g_A)^{j+1}} \quad (71)$$

$$= g_A A_t \sum_{j=0}^{\infty} \frac{(1 - \phi)^j}{(1 + g_A)^{j+1}} \quad (72)$$

$$= \frac{g_A A_t}{1 + g_A} \sum_{j=0}^{\infty} \left(\frac{1 - \phi}{1 + g_A} \right)^j \quad (73)$$

This is a geometric series with ratio $r = \frac{1 - \phi}{1 + g_A}$. Since $0 < \phi < 1$ and $g_A > 0$, we have $0 < r < 1$, so the series converges to $\frac{1}{1 - r}$:

$$A_t^L = \frac{g_A A_t}{1 + g_A} \frac{1}{1 - \frac{1 - \phi}{1 + g_A}} \quad (74)$$

$$= \frac{g_A A_t}{1 + g_A} \frac{1 + g_A}{1 + g_A - (1 - \phi)} \quad (75)$$

$$= \frac{g_A A_t}{1 + g_A} \frac{1 + g_A}{\phi + g_A} \quad (76)$$

$$= \frac{g_A A_t (1 + g_A)}{(1 + g_A)(\phi + g_A)} \quad (77)$$

$$= \frac{g_A A_t}{\phi + g_A} \quad (78)$$

Similarly, for the previous period:

$$A_{t-1}^L = \frac{g_A A_{t-1}}{\phi + g_A} \quad (79)$$

$$= \frac{g_A \frac{A_t}{1 + g_A}}{\phi + g_A} \quad (80)$$

$$= \frac{g_A A_t}{(\phi + g_A)(1 + g_A)} \quad (81)$$

B.3.2 BGP Royalty Revenue

The royalty revenue formula on the balanced growth path with A_{t-1}^L divided by T_t is:

$$\text{Royalty Revenue}_t = \eta \frac{A_t - A_{t-1}}{T_t} \pi + \eta(1 - \phi) \frac{A_{t-1}^L}{T_t} \pi \quad (82)$$

Substituting our expressions:

$$\text{Royalty Revenue}_t = \eta \frac{g_A A_{t-1}}{\frac{A_t}{\alpha}} \pi + \eta(1 - \phi) \frac{\frac{g_A A_t}{(\phi + g_A)(1 + g_A)}}{\frac{A_t}{\alpha}} \pi \quad (83)$$

$$= \eta \frac{g_A \frac{A_t}{1 + g_A}}{\frac{A_t}{\alpha}} \pi + \eta(1 - \phi) \frac{g_A A_t}{(\phi + g_A)(1 + g_A)} \frac{\alpha}{A_t} \pi \quad (84)$$

$$= \eta \frac{g_A \alpha}{1 + g_A} \pi + \eta(1 - \phi) \frac{g_A \alpha}{(\phi + g_A)(1 + g_A)} \pi \quad (85)$$

Factoring out the common terms:

$$\text{Royalty Revenue}_t = \eta \alpha \pi g_A \left[\frac{1}{1 + g_A} + \frac{1 - \phi}{(\phi + g_A)(1 + g_A)} \right] \quad (86)$$

To simplify the expression inside the brackets, we need to find a common denominator:

$$\frac{1}{1 + g_A} + \frac{1 - \phi}{(\phi + g_A)(1 + g_A)} = \frac{\phi + g_A}{(\phi + g_A)(1 + g_A)} + \frac{1 - \phi}{(\phi + g_A)(1 + g_A)} \quad (87)$$

$$= \frac{\phi + g_A + 1 - \phi}{(\phi + g_A)(1 + g_A)} \quad (88)$$

$$= \frac{1 + g_A}{(\phi + g_A)(1 + g_A)} \quad (89)$$

$$= \frac{1}{\phi + g_A} \quad (90)$$

Therefore, the royalty revenue simplifies to:

$$\text{Royalty Revenue}_t = \eta \alpha \pi g_A \frac{1}{\phi + g_A} \quad (91)$$

$$= \eta \alpha \pi \frac{g_A}{\phi + g_A} \quad (92)$$

This means that royalty revenue is proportional to total profits (πA_t) scaled by three factors:

- η : The royalty fee
- α : The technology adoption ratio (A_t/T_t)
- $\frac{g_A}{\phi + g_A}$: The fraction of technologies that remain legitimate

The expression $\frac{g_A}{\phi + g_A}$ represents the fraction of technologies that generate royalties. This fraction approaches 1 when $\phi \rightarrow 0$ (perfect IPR protection) and decreases as ϕ increases (more imitation). It also increases with higher growth rates g_A , indicating that faster technology adoption counteracts imitation by introducing more new technologies that are initially legitimate.

B.3.3 Special Cases

For $\phi = 0$ (perfect IPR protection):

$$\text{Royalty Revenue}_t = \eta\alpha\pi \frac{g_A}{0 + g_A} \quad (93)$$

$$= \eta\alpha\pi \quad (94)$$

For $\phi = 1$ (complete imitation after one period):

$$\text{Royalty Revenue}_t = \eta\alpha\pi \frac{g_A}{1 + g_A} \quad (95)$$

C Model Solution Algorithm

We characterize the BGP of the economy and the associated transitional dynamics. The algorithm proceeds in two stages.

Balanced Growth Path

We start to solve the BGP equilibrium by making the initial guesses for the BGP blueprint allocation and the growth rate $\{\hat{Z}_n^*, g^*\}$:

- (i) Guesses $\{\hat{Z}_n^*, g^*\}$, guess $\{\hat{\omega}_i^*, \eta_{in}^*, \frac{H_{in}^{A*}}{Y^*}\}$ to compute prices, trade shares, outputs, and value functions. We solve for the fixed point with three layers of iterations
 - (a) iterate adoption rate $\frac{H_{in}^{A*}}{Y^*}$ and check against the first-order condition of $\hat{H}_{in}^{A*}$,
 - (b) iterate wages $\hat{\omega}_i^*$ and check against balance-of-payments condition,
 - (c) iterate licensing fee η_{in}^* and check against the first-order condition of Nash bargaining
- (ii) Compute the implied $\frac{H_{in}^{R*}}{Y^*}$ and solve for a new $\{\hat{Z}_n^*, g^*\}$ applying Perron Frobenius Theorem. Iterate until it converges.

Assume the economy reaches the BGP at time T . We compute the transitional path using time path iteration:

- (i) Set the computed BGP value functions as the terminal value and make the initial guess of the time paths of jump variables $\{w^{n,t}, \eta_{in,t}, \frac{H_{in,t}^A}{Y_t}, \frac{H_{n,t}^R}{Y_t}\}_{t=0}^T$.
- (ii) Given the initial state variables $\{Z_{n,0}, A_{in,0}, A_{in,0}^L\}$, we can compute (forward) the time paths of $\{Z_{n,t}, A_{in,t}, T_{n,t}\}_{t=1}^T$
- (iii) Use Balance-of-payments conditions to iterate $w_{n,t}$; Nash-bargaining conditions to iterate $\eta_{in,t}$; First-order conditions of innovation and adoption to iterate $\frac{H_{in,t}^A}{Y_t}, \frac{H_{n,t}^R}{Y_t}$

(iv) Repeat until it converges

Transitional Dynamics

Assume the economy reaches the BGP at some finite horizon T . To compute the transition from an arbitrary initial condition $\{Z_{n,0}, A_{in,0}, A_{in,0}^L\}$ to the BGP, we employ time-path iteration:

- (i) Set the BGP value functions as terminal conditions. Make an initial guess for the time paths of the jump variables $\{w^{n,t}, \eta_{in,t}, H_{in,t}^A/\bar{Y}_t, H_{n,t}^R/\bar{Y}_t\}_{t=0}^T$.
- (ii) Given the state variables $\{Z_{n,0}, A_{in,0}, A_{in,0}^L\}$, compute forward the sequences $\{Z_{n,t}, A_{in,t}, T_{n,t}\}_{t=1}^T$.
- (iii) Update the time paths of the jump variables by imposing equilibrium conditions:
 - Balance-of-payments conditions to iterate on wages $w_{n,t}$,
 - Nash-bargaining conditions to iterate on licensing fees $\eta_{in,t}$,
 - First-order conditions of innovation and adoption to iterate on $H_{in,t}^A/\bar{Y}_t$ and $H_{n,t}^R/\bar{Y}_t$.
- (iv) Repeat until the entire system converges to a consistent transition path.

D BGP Analysis: An Increase of Geopolitical Distance

To illustrate how geopolitical distance affects equilibrium outcomes in the BGP, we analyze a three-country model where countries differ only in their IPR enforcement. Countries 1 and 3 maintain perfect IPR enforcement ($\xi_i = 1$), while country 2's enforcement varies between 0 (no enforcement) and 1 (perfect enforcement). The parametrization follows Table 12.

The discount rate $\beta = 0.98$ corresponds to an annual interest rate of approximately 2%. We set the elasticity of substitution between varieties $\sigma = 5$, consistent with estimates in the international trade literature. The innovation and adoption curvature parameters (β^R and β^A) are both set to 0.50, reflecting diminishing returns to R&D investment.

For the technology transfer parameters, we set the innovator's baseline bargaining power $\rho = 0.45$. Adoption efficiency varies by country pair, with higher values for cross-country adoption to reflect the greater potential gains from international technology transfer.

The political distance between countries 1 and 2 varies so that the breach probability is between 0 (no political tension) and 0.35. All other country pairs maintain a political

Parameter	Description	Value
β	Discount rate	0.98
β^A	Adoption curvature	0.50
β^R	Innovation curvature	0.50
σ	Elasticity of Substitution	5
ρ	Innovator's baseline bargaining power	0.25
$\bar{\epsilon}_{in}$	Baseline adoption efficiency	1 for $i = n$, 7.5 for $i \neq n$, 2.5 for $i \neq n$
d_{in}^G	Geographic distance	1 for $i = n$, 2.5 for $i \neq n$
d_{in}^P	Political distance	[1,1.693] for $in = 12, 21$, 1 otherwise
κ^G	Trade cost elasticity to geographic distance	1
κ^P	Trade cost elasticity to political distance	1
τ_{in}, χ_{in}	Tariff and technology export control	0
L_i, Ω_i	Labor endowment and productivity	1
λ_i	Innovation efficiency	[0.1250, 0.0625, 0.1000]
ξ_{in}	IPR enforcement	0,1 for $i = 2$ and $i \neq n$, 1 otherwise
κ^ϕ	Elasticity of breach to political distance	1

Table 12: Simulation parametrization

distance of 1. The geographical distance is normalized to 1 for domestic transactions and 2.5 for international transactions. Innovation efficiency differs between countries, with country 1 ($\lambda_1 = 0.1250$) being the most innovative, followed by country 3 ($\lambda_3 = 0.10$) and country 2 ($\lambda_2 = 0.0625$).

Figure 9 illustrates the main channels. An increase in ϕ_{21} raises the probability of contractual breach, which decreases the adoption probability ϵ_{21} and the stock of adopted technologies A_{21}/T_2 . Innovators respond by charging higher royalty rates η_{21} , yet this adjustment cannot compensate for the sharp contraction in licensed technologies. As a result, royalty payments $RP_{21}/\bar{Y}$ decline.

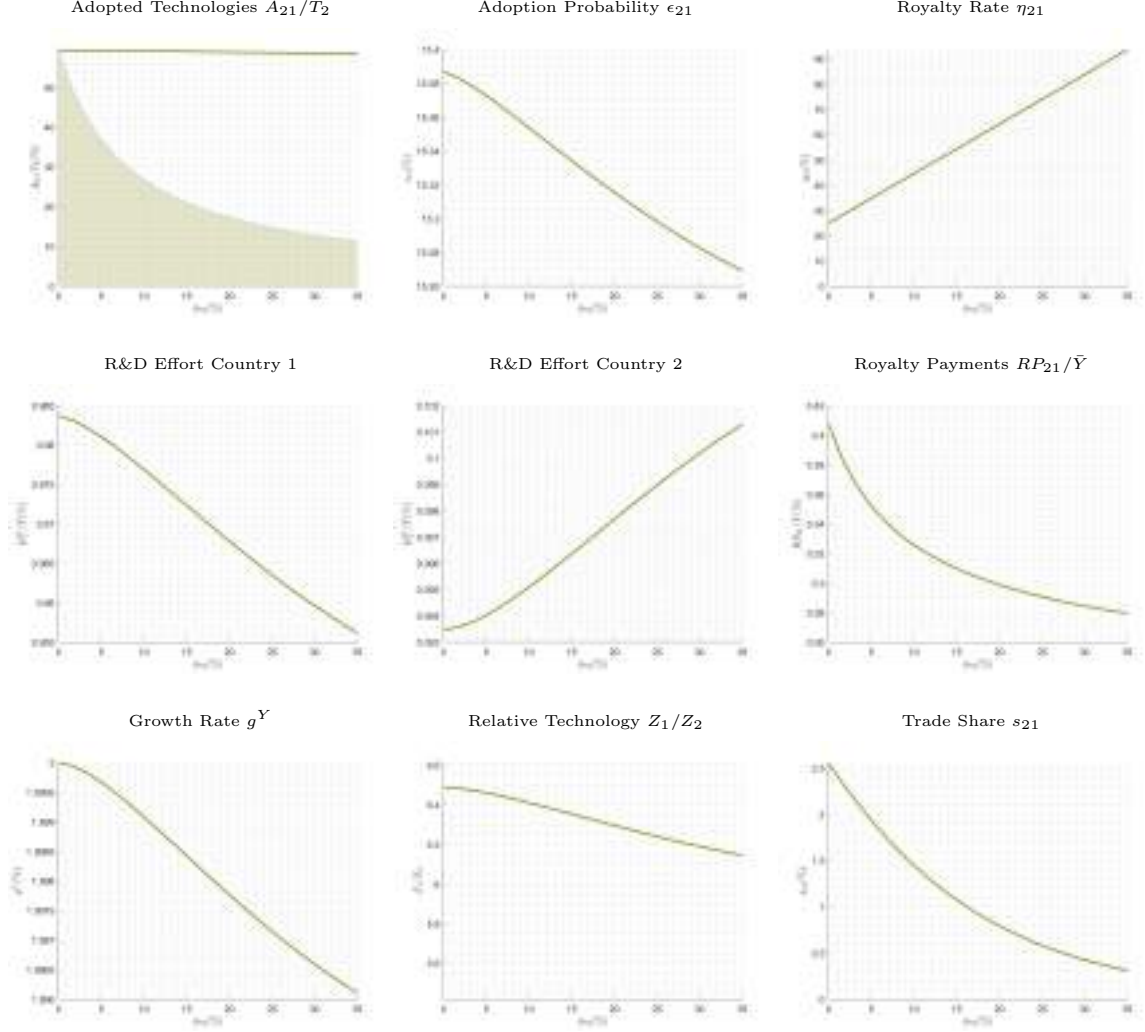
The fall in adoption weakens innovation incentives in the leading economy: country 1 reduces its R&D effort, $H_1^R/\bar{Y}$. By contrast, country 2 reallocates resources toward imitation-driven effort, slightly raising its $H_2^R/\bar{Y}$. This asymmetry reflects the model's central friction: weak IPR enforcement allows the follower to free-ride on the innovator under political tensions.

At the aggregate level, the decline in adoption and innovation lowers the growth rate g^Y . Moreover, relative technology levels shift in favor of the follower: the ratio Z_1/Z_2 falls, capturing the erosion of technological leadership in the innovating country. Finally, the bilateral trade share s_{21} declines, consistent with the standard gravity channel, but its magnitude is smaller than the collapse in technology flows.

Technology transfers are *doubly exposed* to geopolitical frictions, through reduced market size and increased breach risk, making them more sensitive than merchandise trade to political distance. This explains both the efficiency costs of fragmentation and the

strategic incentives for governments to intervene in order to preserve relative technological advantage.

Figure 9: Effect of an increase in geopolitical distance between countries 1 and 2 on Balanced Growth Path allocations.



Notes: Simulation of the three-country model described in Table 12. Countries 1 and 3 maintain perfect IPR enforcement ($\xi = 1$), while country 2 has weak IPR enforcement ($\xi = 0$). The political distance between countries 1 and 2 increases so that the breach probability rises from 0 to 0.35.

To assess the relative importance of the two channels through which geopolitical distance operates, we compare the benchmark against two counterfactuals: (i) no market-size effect ($\kappa^P = 0$), so that geopolitical distance only increases breach risk; and (ii) only market-size effect ($\xi_2 = 1$), so that distance affects trade costs but contracts are perfectly enforced. The results show that the benchmark response is a combination of both mechanisms: breach risk dominates the contraction in adoption, while market-size effects amplify the decline in innovation and growth. When the market-size channel is shut down, surplus is reallocated toward the innovator, so that Z_1/Z_2 actually rises and a government concerned with relative technological leadership would have little reason

to intervene. It is only when both channels are present that geopolitical distance reduces Z_1/Z_2 , erodes innovation incentives, and creates the strategic motive for policy intervention observed in practice.

Figure 10 decomposes the benchmark results into two counterfactuals to isolate the channels through which geopolitical distance affects equilibrium outcomes. The solid line corresponds to the benchmark, the dotted blue line to the case with no market size effect ($\kappa^P = 0$), and the dotted black line to the case with only the market size effect ($\xi_2 = 1$).

A somewhat counterintuitive result emerges when we shut down the market-size channel ($\kappa^P = 0$). In this case, greater geopolitical distance only raises breach risk, prompting higher royalty rates that shift surplus toward the innovator. Adoption does not collapse, and country 1's R&D incentives actually strengthen. This is not a prediction of the full model, but rather an artefact of isolating the breach channel: absent market size effects, fragmentation simply redistributes rents in favor of the leader. As a consequence, Z_1/Z_2 rises, so the leader's relative technological position improves. In such an environment, a government motivated by national security concerns would see little reason to intervene.

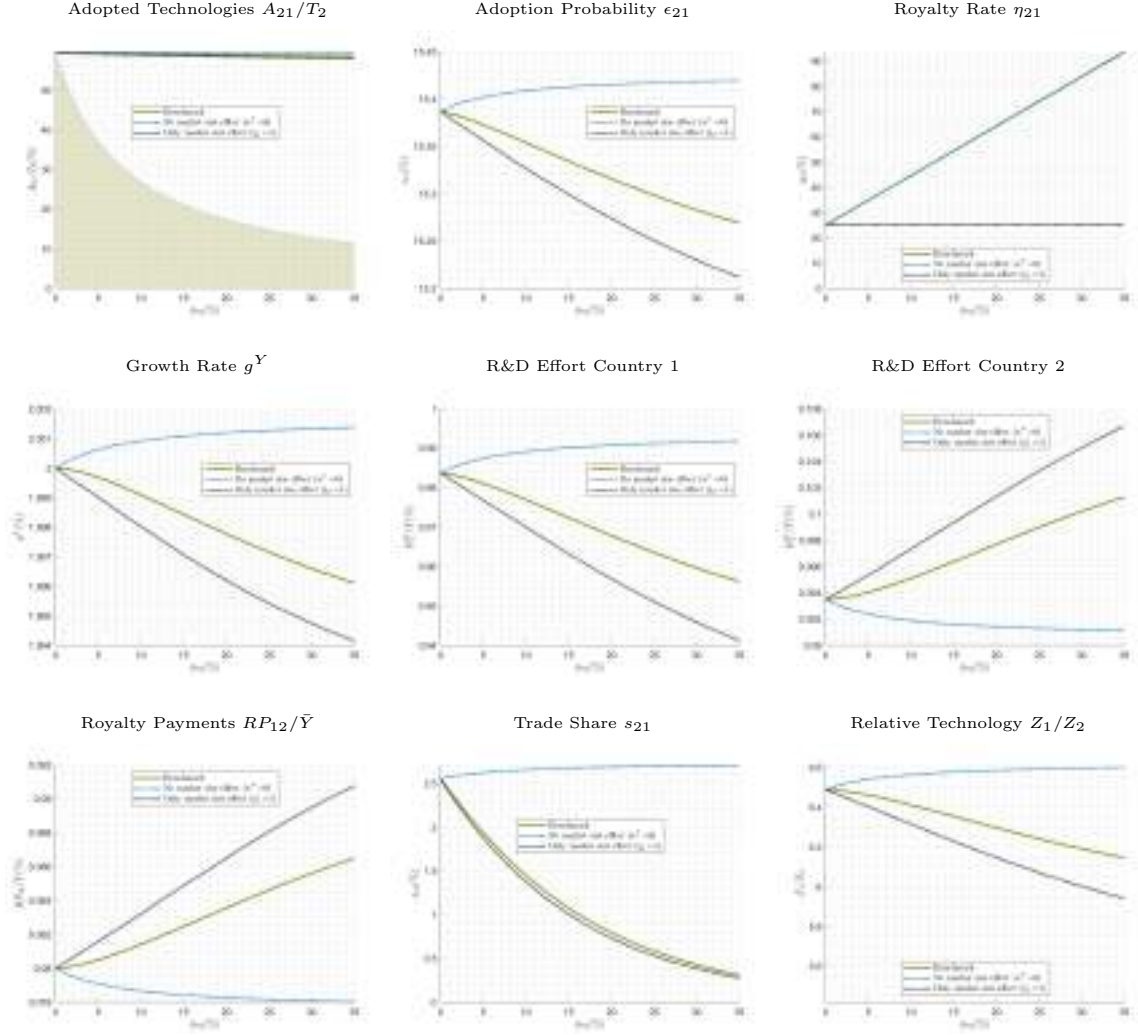
It is only when market-size effects are also present that geopolitical distance lowers adoption, depresses royalty payments, and reduces innovation incentives. In this benchmark case, the decline in Z_1/Z_2 creates a clear strategic motive for intervention. The strong role of market size is consistent with the data: geopolitical distance reduces both trade flows and royalty payments, implying that fragmentation undermines innovation not only by raising breach risk but also by shrinking market opportunities. Hence both channels are essential for capturing the observed sensitivity of technology flows and for rationalizing why governments intervene on national security grounds.

In the absence of market size effects ($\kappa^P = 0$), adoption collapses as breach risk rises, leading to a sharp fall in A_{21}/T_2 and ϵ_{21} . Royalty rates η_{21} increase strongly, but total royalty payments remain depressed. Innovation in country 1 falls moderately, while country 2's imitation-driven effort rises only slightly. By contrast, when only market size effects operate ($\xi_2 = 1$), adoption probabilities remain constant, but the decline in bilateral trade shares reduces the profitability of R&D, lowering growth and shifting relative technology levels.

Overall, the benchmark combines both channels: breach risk dominates the adoption margin, while market size effects reinforce the contraction in innovation and the decline in long-run growth.

Finally, to assess the role of endogenous royalty renegotiation, we contrast the benchmark with a counterfactual in which the royalty fee is fixed at $\rho = 0.25$, so that it does not adjust to breach risk. The inability to raise royalty fees under political tension amplifies the adverse effects of geopolitical distance: adoption probabilities rise mechanically, but innovators' revenues collapse, sharply reducing R&D in country 1, accelerating catch-up

Figure 10: Benchmark vs. counterfactuals without market size effect ($\kappa^P = 0$) and with only market size effect ($\xi_2 = 1$).



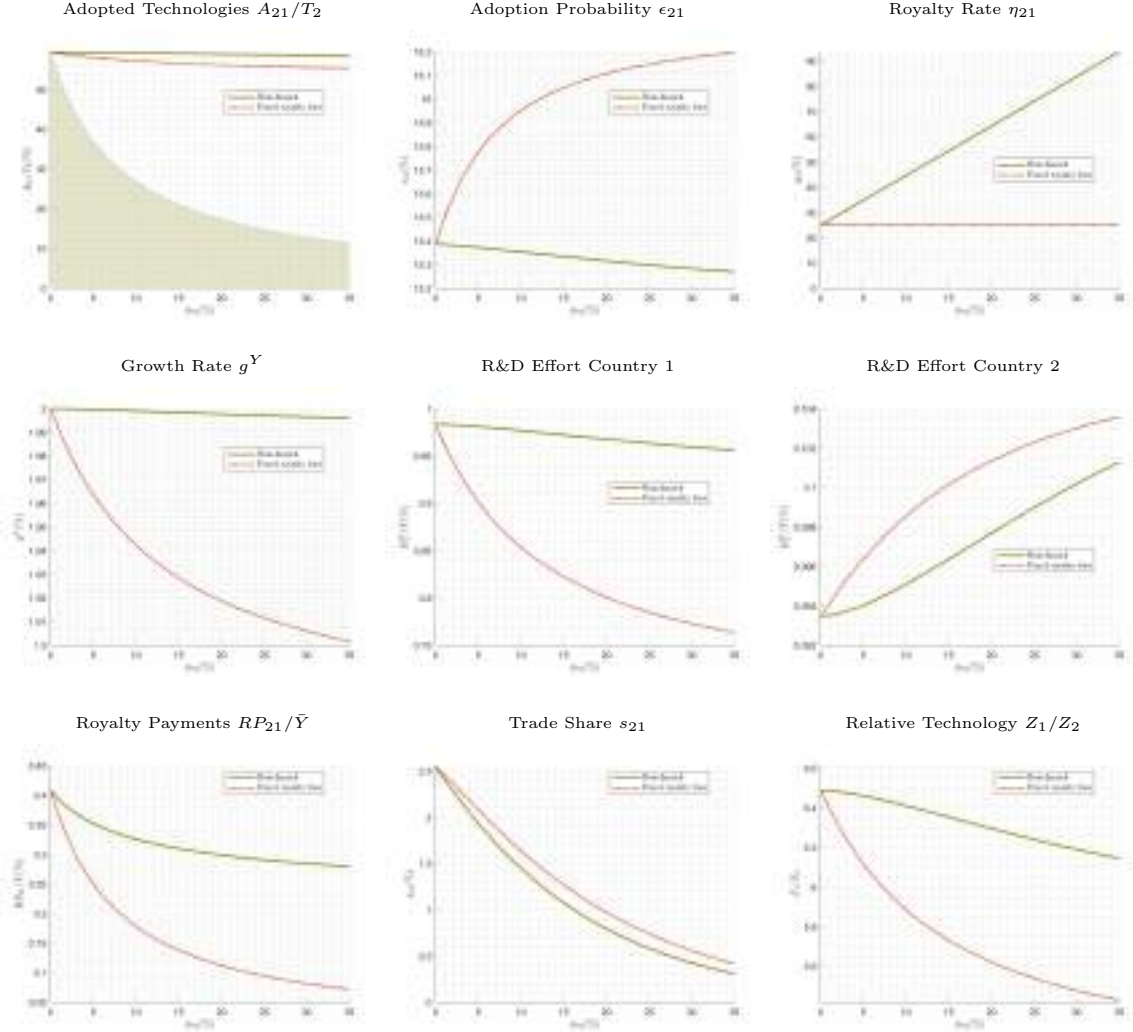
Notes: The benchmark includes both channels: trade costs and breach risk rise with geopolitical distance. In the *no market size effect* case (blue dotted), only breach risk matters, so adoption falls strongly but trade shares remain flat. In the *only market size effect* case (black dotted), adoption is insulated by perfect IPR enforcement, but the contraction in trade shares reduces innovation incentives. The benchmark path lies between these polar cases, indicating that breach risk is the primary force behind the collapse in technology transfer, while market size amplifies the effects on R&D and growth.

by country 2, and generating a larger decline in aggregate growth. This illustrates that renegotiated royalty rates partly insulate innovators.

Figure 11 compares the benchmark equilibrium with a counterfactual in which the royalty fee is kept constant at $\rho = 0.25$. In this scenario, royalty rates do not adjust upward as breach risk rises, eliminating the contractual margin of protection for innovators.

The comparison shows that endogenous royalty renegotiation mitigates, but does not eliminate, the adverse effects of geopolitical distance. Without renegotiation, innovators bear the full burden of breach risk, licensing collapses, and global growth suffers more.

Figure 11: Benchmark vs. fixed royalty fees ($\rho = 0.25$).



Notes: With fixed royalty fees, adoption probabilities ϵ_{21} rise with distance because adopters face lower contractual costs, but innovators cannot adjust royalties to reflect higher breach risk. Consequently, royalty payments RP_{21} fall sharply, undermining R&D incentives in country 1 and leading to a faster relative catch-up of country 2 (Z_1/Z_2 declines steeply). The aggregate growth rate g^Y falls much more than in the benchmark, showing that renegotiation of royalty fees plays a stabilizing role in cushioning the growth impact of geopolitical fragmentation.