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Technology, Geopolitics, and Trade*†

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Abstract

We study how geopolitical fragmentation shapes cross-border technology licensing and innovation incentives. We show that bilateral royalty flows vary with geopolitical distance differently from goods trade, and that this relationship depends on intellectual property enforcement. To interpret these facts, we develop a growth-trade model in which geopolitical risk weakens licensing enforceability when intellectual property rights are poorly protected. Royalty payments reflect both technology adoption and licensing prices: weaker enforcement can reduce diffusion while inducing firms to reprice contracts. Reduced market size lowers returns to frontier technologies, whereas repricing can redirect innovation toward the technological leader, generating asymmetric welfare effects.

JEL classification: F63, O14, O33, O34.

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

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1 Introduction

Cross-border technology diffusion is a key determinant of global innovation, yet rising geopolitical fragmentation increasingly shapes how firms organize the transfer of ideas across borders. Technologies move internationally through different arrangements, ranging from arm's-length licensing to internalization within multinational firms, that differ in their reliance on formal legal enforcement. Licensing contracts depend especially on the enforceability of intellectual property rights and other contractual protections, making them particularly exposed to geopolitical conditions. This paper studies how geopolitical fragmentation is reflected in the contractual structure of international technology transfer, and how these changes can alter innovation incentives.

The question is increasingly important because geopolitical considerations now play a central role in the organization of innovation and technology diffusion across countries (Chatterji and Murray, 2025). Concerns about economic security and technological sovereignty have raised the policy relevance of cross-border technology transactions, especially in sectors where intellectual property and legally enforceable knowledge transfers are central. Yet despite this growing attention, the mechanism linking political risk, technology transfer contracts, and the global allocation of innovation remains poorly understood.

We first examine this contractual channel empirically. Royalty flows, the observable counterpart of arm's-length technology transfer, are more sensitive to geopolitical distance than merchandise trade, and this sensitivity is concentrated in countries with weak IPR enforcement. This pattern is consistent with the idea that legally mediated technology transactions are especially exposed to political and enforcement risk. Interpreting the evidence, however, requires confronting an identification problem. Royalty flows combine price and quantity margins, making it difficult to distinguish changes in the price of licensing from changes in technology adoption itself. A deterioration in geopolitical relations may simultaneously reduce compliant adoption and increase the compensation innovators require to license abroad. Stronger IPR protection attenuates these responses by improving contract enforceability, but reduced-form evidence alone cannot separately identify the underlying margins. This motivates a structural framework that isolates the role of licensing contracts in shaping innovation outcomes.

We develop a multi-country endogenous growth model in which geopolitical fragmentation affects innovation through both market access and the enforceability of international technology licensing contracts. Cross-border technology transfer occurs through licensing agreements subject to enforcement risk. Because licensing separates ownership of ideas from their use abroad, political risk affects compliant adoption as well as the royalties required by innovators. Geopolitical distance operates through two channels. The first is an enforcement channel: higher geopolitical distance raises the probability of contractual breach and induces endogenous royalty repricing. Consistent with recent work on contractibility, which emphasizes that enforcement depends on the ability of parties to generate legally verifiable evidence of deviations from agreed terms (Corrao, Flynn, and Sastry, 2025), we interpret this risk as a reduced-form representation of the greater difficulty of monitoring, verifying, and punishing contractual deviations across jurisdictions. Since innovators and adopters bargain over royalty fees, enforcement risk affects both the expected value of technology transfer and the division of surplus between licensors and licensees. Along the balanced growth path, royalty adjustment offsets the direct effect of breach risk on contractual surplus shares conditional on successful adoption; during transitions, however, licensing relationships formed under different geopolitical environments coexist, so contractual conditions adjust gradually and propagate shocks over time. The second is a market-size channel: fragmentation raises trade costs and compresses adopters' profits, reducing the scale over which technologies can be profitably adopted and licensed internationally. Through these channels, geopolitical shocks jointly determine licensing prices, adoption quantities, and innovation incentives.

The interaction between these forces generates a central theoretical implication. A natural prior is that geopolitical fragmentation uniformly reduces innovation incentives by shrinking market access. The model shows why this need not be true. Holding market size fixed, higher enforcement risk raises innovation effort in the technological leader and lowers it in the follower: endogenous royalty repricing shifts the division of the global knowledge market toward the frontier economy. By contrast, the market-size effect works in the opposite direction. Lower adopter profits compress demand for frontier technologies and shift R&D toward less innovative locations. The overall response of innovation to fragmentation therefore depends on which force dominates. Importantly, the enforcement channel implies that geopolitical tensions may increase innovation in the technological leader even as they reduce technology diffusion and raise contractual frictions. This prediction does not arise in models with fixed licensing terms or without enforcement frictions, where fragmentation affects innovation only through market size and adoption incentives.

To assess the quantitative importance of these mechanisms, we take the model to the data. We calibrate the global economy to trade flows, royalty payments, R&D intensities, patent stocks, and international citation patterns across eight regions. The multi-region structure disciplines the geography of innovation, adoption, and licensing opportunities faced by firms, while allowing the counterfactual analysis to focus on a particularly bilateral margin in frontier technology markets: fragmentation between the United States and China. This distinction is important because the effects of a bilateral geopolitical shock depend not only on the affected pair, but also on how technologies, goods, and royalty flows are reallocated through the rest of the world.

The calibrated model implies that geopolitical fragmentation generates a price–quantity wedge in international technology transfer: royalty rates rise through endogenous contract repricing, while compliant adoption falls. In the calibrated economy, the market-size channel dominates the enforcement channel. As a result, fragmentation reduces cross-border technology diffusion, lowers frontier innovation, and slows long-run growth. Although firms renegotiate licensing contracts in response to greater geopolitical risk, the decline in adoption dominates, leading to lower royalty payments overall. Fragmentation also reallocates research activity across countries and narrows technological gaps between leaders and followers. The associated welfare effects are unevenly distributed across economies.

The counterfactual results also point to a policy question. Because licensing frictions affect the future allocation of innovation, private licensing decisions may not coincide with national objectives. Firms choose technology-transfer arrangements based on expected enforcement conditions and current surplus, but do not internalize how diffusion today shapes future technological leadership. Governments may therefore value international technology transfers not only for their contemporaneous consumption and diffusion gains, but also for their effect on the future location of innovative activity. This dynamic wedge provides a rationale for studying restrictions on technology transfers, such as export controls, as strategic policy instruments rather than simply barriers to exchange. We characterize optimal policy under alternative government objectives. Under a standard consumption-based welfare criterion, unilateral export controls are not optimal because they reduce the gains from international technology diffusion. Once governments place value on technological leadership, however, the policy prescription changes: restrictions on technology transfers can reallocate future innovation activity across countries even when they reduce contemporaneous welfare. This mechanism is consistent with recent work showing that geopolitical objectives can rationalize trade and industrial policies that would be inefficient under a purely consumption-based welfare criterion (Becko and O'Connor, 2024; Becko, Grossman, and Helpman, 2025; Clayton, Maggiori, and Schreger, 2025).

Related Literature This paper connects to several strands of research on growth, trade, technology diffusion, and geoeconomic fragmentation. A large literature studies how market size and openness shape innovation incentives in open economies (Grossman and Helpman, 1991; Eaton and Kortum, 2001). Building on this tradition, Santacreu (2015) develops a quantitative framework in which trade facilitates the international diffusion of ideas and affects innovation incentives across countries, while Cai, Li, and Santacreu (2022) show how knowledge diffusion, trade, and innovation interact across countries and sectors. Related empirical work uses cross-border patenting to measure international technology diffusion and its relationship to globalization and development (LaBelle et al., 2023). Recent text-based evidence also shows that new technologies originate in highly concentrated locations and diffuse only gradually across space, occupations, and skill groups (Kalyani et al., 2025).

More recent work studies how policy can affect the direction and geography of technology diffusion in dynamic trade environments (Bai, Jin, and Lu, 2023, 2025). Closely related, Hémous et al. (2025) study optimal patent protection in an open-economy environment with trade and innovation. We contribute to this literature by introducing geopolitical distance and institutional enforcement as determinants of the contractual environment in which technology is transferred. Our focus on how geopolitical fragmentation reallocates innovation incentives is also related to recent work showing that the composition of inventive activity matters for aggregate productivity growth (Kalyani, 2026).

The paper is also related to work on technology diffusion, licensing, intellectual property rights, and imperfect enforcement (Glass and Saggi, 1999; Acemoglu and Akcigit, 2012; Branstetter, Fisman, and Foley, 2006). Existing frameworks emphasize the role of intellectual property protection and imitation risk, but typically treat licensing terms as fixed or exogenous. Recent evidence shows that royalty rates depend not only on technology quality but also on bargaining conditions and contract characteristics (Kankanhalli and Kwan, 2023). Motivated by these findings, we model royalty rates as endogenous contract terms that respond to geopolitical risk. Higher breach risk increases the compensation innovators require to license technologies abroad, creating a wedge between observed royalty payments and underlying technology adoption. We extend the technology-diffusion literature by embedding Nash bargaining with breach risk into a multi-country growth framework in which geopolitical shocks affect contractual terms, technology adoption, wages, and long-run innovation dynamics.

Our analysis is related to Lam (2024), who studies how countries choose IPR protection in a global environment with innovation and imitation. We differ by treating geopolitical distance as a bilateral source of contractual breach risk and by allowing royalty terms to reprice endogenously in response to that risk. Our analysis also relates to work on trade agreements, international commitment, and incomplete contracts. A central insight of the trade-agreement literature is that international agreements can discipline trade-policy discretion and support cross-border exchange when governments face domestic or strategic incentives to distort trade (Bagwell and Staiger, 1999; Maggi and Rodriguez-Clare, 1998, 2007; Bagwell and Staiger, 2011). Santacreu (2025) extends this logic to dynamic trade agreements with intellectual property provisions, where IP commitments shape technology transfer through licensing contracts. Our setting differs because the relevant commitment problem is not only trade policy, but also private contractual enforcement in cross-border technology licensing. In this sense, our framework complements the trade-agreement literature by studying how geopolitical risk operates through private contracts even in the absence of formal changes in trade policy. It also connects to the incomplete-contracting tradition (Grossman and Hart, 1986; Hart and Moore, 1990; Antras, 2003) by studying how politically contingent enforceability affects licensing terms, technology diffusion, and long-run innovation dynamics in a multi-country environment.

More broadly, our paper contributes to recent work on geoeconomic fragmentation, geoeconomic power, and strategic technology policy (Aiyar, Presbitero, and Ruta, 2023; Bai, Jin, and Lu, 2023, 2025; Fornaro and Wolf, 2025; Clayton, Maggiori, and Schreger, 2026, 2025; Liu and Yang, 2025; Kleinman, Liu, and Redding, 2024). This literature studies how geopolitical considerations reshape international economic relationships through concerns about dependence, coercion, and economic security. Kleinman, Liu, and Redding (2024) show that trade exposure shapes political alignment, while Liu and Yang (2025) measure international power arising from asymmetric import dependence and show that countries strategically adjust trade exposure when geopolitical relations deteriorate. Existing work emphasizes the possibility that foreign suppliers may withhold critical goods or intermediate inputs, generating vulnerabilities that can motivate industrial policy, supply-chain diversification, or export controls. For example, Corrao, Flynn, and Sastry (2025) show that exposure to foreign political risk can stimulate domestic innovation as firms seek to reduce reliance on vulnerable foreign suppliers. Similarly, Alfaro and coauthors (2025) show that China's rare-earth export restrictions induced innovation in downstream industries outside China by encouraging the development of technologies that economize on scarce inputs. We study a complementary channel: dependence in markets for ideas rather than goods. Because technology transfers are governed by licensing contracts, geopolitical tensions affect not only sourcing patterns but also enforcement risk, contractual prices, and the future distribution of technological leadership.

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 and the balanced growth path. Section 4 analyzes the mechanisms through which geopolitical tensions affect licensing, innovation, technology diffusion, and transition dynamics. Section 5 presents the quantitative analysis and policy experiments. Section 6 concludes.

2 Empirical Evidence

This section documents two empirical regularities that motivate the model. First, cross-border royalty payments respond differently to geopolitical distance than merchandise trade. Second, the relationship between geopolitical distance and royalty payments varies systematically with the strength of IPR protection in the destination country. These patterns are informative because royalty payments arise from formal licensing agreements and are therefore especially exposed to the enforceability of cross-border contracts.

Our data cover bilateral flows among 43 countries over 2007–2021. Merchandise trade data are from BACI-CEPII, and royalty and license fee flows are from the OECD

International Trade in Services statistics. Geopolitical distance, denoted by GP_{ij}, is the ideal-point distance between countries i and j in United Nations General Assembly voting, following Bailey, Strezhnev, and Voeten (2017) and Airaudo et al. (2025). We use the post-2007 average of this measure to capture persistent differences in political alignment. IPR protection is measured by the International Property Rights Index and normalized to lie between zero and one.

We estimate gravity equations for merchandise exports and royalty payments using Poisson Pseudo-Maximum Likelihood (Yotov et al., 2016). The baseline specification is

$$\begin{aligned}\mu_{ijt} \equiv E[Y_{ijt} \mid \mathcal{X}_{ijt}] = \exp\big[&\beta_1 \log GP_{ij} + \beta_2 \big(\log GP_{ij} \times IPR_j\big) \\ &+ X'_{ijt}\beta + \delta_{it} + \gamma_{jt}\big],\end{aligned} \tag{1}$$

where Y_{ijt} denotes either merchandise exports or royalty payments from country i to country j in year t. The vector X_{ijt} includes standard gravity controls: log geographic distance, contiguity, common language, and trade-agreement indicators. Exporter–year fixed effects δ_{it} and importer–year fixed effects γ_{jt} absorb time-varying country characteristics and multilateral resistance terms. The standalone IPR term is absorbed by the importer–year fixed effects.

The coefficient β_1 captures the association between geopolitical distance and bilateral flows when the interaction is omitted. With the interaction, the geopolitical-distance elasticity of expected bilateral flows is

$$\mathcal{E}_{GP}(IPR_j) \equiv \frac{\partial \log \mu_{ijt}}{\partial \log GP_{ij}} = \beta_1 + \beta_2 IPR_j. \tag{2}$$

Thus, β_2 measures how the elasticity with respect to geopolitical distance varies with destination-country IPR protection.[1]

We interpret the estimates as conditional associations rather than causal effects. Political alignment and bilateral economic relationships may co-evolve, and exporter–year and importer–year fixed effects do not absorb bilateral time-varying confounders. The purpose of the exercise is to document the differential sensitivity of trade and royalty payments to geopolitical distance.

[1] The interaction coefficient is not, by itself, a cross-partial derivative of the level of expected flows. The cross-partial derivative of μ_{ijt} depends on the predicted conditional mean and on both β_1 and β_2.

Table 1: Geopolitical Distance, IPR Protection, and Bilateral Flows

	No Interaction		With Interaction	
	Trade	Royalties	Trade	Royalties
Log Geopolitical Distance	-0.034***	0.149***	-0.169***	-0.536***
	(-3.47)	(7.00)	(-7.59)	(-11.28)
Geo × IPR	–	–	0.225***	0.916***
			(7.09)	(14.14)
FTA/WTO	0.460***	0.097*	0.452***	0.211***
	(16.43)	(2.01)	(16.02)	(4.47)
Log Distance	-0.596***	-0.350***	-0.601***	-0.331***
	(-55.33)	(-16.17)	(-55.94)	(-14.70)
Contiguity	0.558***	-0.145*	0.571***	-0.096
	(19.93)	(-2.25)	(20.32)	(-1.45)
Common Language	0.079**	0.107	0.080**	0.047
	(2.66)	(1.87)	(2.69)	(0.83)
Observations	25,284	27,090	25,284	27,090

Notes: PPML estimates with exporter–year and importer–year fixed effects. t statistics are in parentheses. Implied geopolitical-distance elasticities at different percentiles of IPR protection are computed as linear combinations of the coefficient on log geopolitical distance and the Geo × IPR interaction; standard errors use the full variance–covariance matrix of these estimates.
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 1 reports the results. Columns 1 and 2 omit the IPR interaction. Geopolitical distance is negatively associated with merchandise trade but positively associated with royalty payments. The positive coefficient for royalties should not be interpreted as evidence that geopolitical distance raises technology diffusion. Royalty payments combine a licensing price and a quantity of compliant technology use. A deterioration in geopolitical relations may reduce compliant adoption while increasing the compensation innovators require to license technology abroad.

Columns 3 and 4 allow the association with geopolitical distance to vary with destination-country IPR protection. For both trade and royalties, stronger IPR protection makes the geopolitical-distance elasticity more positive. The gradient, however, is much larger for royalty payments. The estimated interaction is 0.916 for royalties, compared with 0.225 for merchandise trade. This difference suggests that institutional protection is especially relevant for transactions involving formal technology licensing.

The magnitudes are economically meaningful. For royalties, the implied geopolitical-distance elasticity increases from approximately -0.03 at the 25th percentile of IPR protection to 0.10 at the median and 0.28 at the 75th percentile. For merchandise trade, the corresponding elasticities remain close to zero, increasing only from approximately -0.05 to -0.01 and 0.03. Thus, the sensitivity of royalty payments to geopolitical distance varies substantially with destination-country IPR protection, whereas the analogous variation for merchandise trade is modest.

The estimates point to two robust empirical patterns. First, royalty payments and merchandise trade differ in their conditional relationship with geopolitical distance. Second, the royalty-distance relationship varies with destination-country IPR protection. Together, these patterns suggest that geopolitical conditions are reflected not only in the movement of goods, but also in legally mediated transactions over technology.

This interpretation has limits. The reduced-form evidence cannot distinguish whether changes in royalty payments arise from licensing prices, compliant technology adoption, or both. It also does not require contractual enforcement to be the only reason royalties differ from merchandise trade. The structural model developed next uses these facts as discipline while separating the price, adoption, and market-size margins through which geopolitical frictions shape technology diffusion and innovation.

3 Model

Guided by the empirical patterns, we develop a model in which geopolitical tensions affect the enforcement of international licensing contracts and, through them, the allocation of technology across countries. There are M countries in the world economy, indexed by i, n, and m. Time is discrete and indexed by t.

Each country is populated by four types of agents. Final-good producers operate under perfect competition and combine traded intermediate varieties into a homogeneous consumption good. Intermediate-good producers are monopolistically competitive firms that use labor to produce differentiated varieties. Intermediate varieties are internationally traded and are subject to iceberg trade costs. Innovators invest in R&D to create new technologies, while adopters invest resources to implement these technologies and produce new varieties. The interaction between innovators and adopters is governed by Nash bargaining over licensing agreements, which determines royalty payments and the extent of legitimate technology transfer.

3.1 Households

Each country is inhabited by a representative household that maximizes lifetime utility,

$$U_{n,t} = \sum_{s=t}^{\infty} \beta^{s-t} \ln(C_{n,s}), \tag{3}$$

where β denotes the discount factor and $C_{n,s}$ is consumption in country n at time s. The household faces the budget constraint

$$P_{n,t}C_{n,t} + P_{n,t}B_{n,t+1} = W_{n,t}L_{n,t} + \Pi^{\text{all}}_{n,t} + P_{n,t}R_tB_{n,t}, \tag{4}$$

where $P_{n,t}$ is the aggregate price index, $W_{n,t}$ is the wage rate, $L_{n,t}$ is the labor endowment, $\Pi^{\text{all}}_{n,t}$ denotes aggregate profits from all firms owned by the household, and $B_{n,t}$ represents holdings of a one-period risk-free bond that pays the gross interest rate R_t. The representative household consumes, saves through bond holdings, supplies labor inelastically, and owns all firms operating in the economy.

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

$$Y_{n,t} = \left(\sum_{i=1}^{M} \int_0^{T_{i,t}} x_{ni,t}(j)^{\frac{\sigma-1}{\sigma}}\, dj \right)^{\frac{\sigma}{\sigma-1}}, \tag{5}$$

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

$$x_{ni,t}(j) = \left(\frac{p_{ni,t}(j)}{P_{n,t}} \right)^{-\sigma} Y_{n,t}, \tag{6}$$

where $p_{ni,t}(j)$ is the price paid in country n for intermediate input j produced by country i. The aggregate price index is

$$P_{n,t} = \left(\sum_{i=1}^{M} \int_{0}^{T_{i,t}} p_{ni,t}(j)^{1-\sigma} \, dj \right)^{\frac{1}{1-\sigma}}. \tag{7}$$

3.3 Intermediate Production

There is a continuum of monopolistically competitive intermediate producers. A producer in country n produces variety j with a linear technology

$$y_{n,t}(j) = \Omega_{n,t} l_{n,t}(j), \tag{8}$$

where $\Omega_{n,t}$ is country-specific productivity and $l_{n,t}(j)$ is labor hired by the firm. Given input demand, an intermediate producer in country n maximizes

$$\pi_{n,t}(j) = \sum_{i=1}^{M} p_{in,t}(j) x_{in,t}(j) - W_{n,t} l_{n,t}(j), \tag{9}$$

where $x_{in,t}(j)$ is demand in destination i for a variety produced in origin n.

3.4 International Trade

Intermediate goods are traded internationally. Trade is costly because of iceberg trade costs $d_{in,t}$, which are parameterized as

$$d_{in,t} = \left(d_{in}^{G} \right)^{\kappa^{G}} \left(d_{in,t}^{P} \right)^{\kappa^{P}}. \tag{10}$$

This specification separates trade barriers into geographic distance, d_{in}^{G}, and geopolitical distance, $d_{in,t}^{P}$, allowing the model to discipline the responsiveness of trade flows to both measures. The import share in country n accounted for by intermediates from country i is

$$s_{ni,t} = \frac{\Omega_{i,t}^{\sigma-1} T_{i,t} \left(W_{i,t} d_{ni,t} \right)^{1-\sigma}}{\sum_{m=1}^{M} \Omega_{m,t}^{\sigma-1} T_{m,t} \left(W_{m,t} d_{nm,t} \right)^{1-\sigma}}. \tag{11}$$

3.5 Innovation

In each country n, innovators invest $H_{n,t}^{R}$ units of final output to introduce new ideas or technologies. The number of new technologies invented is

$$\Delta Z_{n,t} = \lambda_n Z_{n,t}^{w} \left(\frac{H_{n,t}^{R}}{\bar{Y}_t} \right)^{\beta^R}, \tag{12}$$

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

$$Z_{n,t}^{w} = \sum_{i=1}^{M} \gamma_{ni} Z_{i,t}, \tag{13}$$

where $\gamma_{ni} \in [0,1]$ is an exogenous weight that reflects the ease with which ideas from country i diffuse to country n. Thus, $Z_{n,t}^{w}$ measures the global knowledge pool accessible to country n at time t, before considering adoption for production.

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

$$V_{n,t} \left(Z_{n,t+1} - Z_{n,t} \right) - P_{n,t} H_{n,t}^{R}, \tag{14}$$

where $V_{n,t}$ is the value of an innovation. Ideas are blueprints that can be used in the production of differentiated intermediate goods only after adoption.

3.6 Adoption and Technology Licensing

This subsection describes how foreign technologies enter production and generate royalty payments. Firms in destination country i invest resources to adopt technologies invented in origin country n. Upon successful adoption, the adopter uses the technology in production and enters a licensing contract with the innovator. Because enforcement is imperfect, the stock of technologies used in production need not coincide with the stock of technologies that generate royalty payments. We first describe adoption and then characterize licensing contracts and their enforcement.

Adoption. For each origin–destination pair (i, n), adoption is represented by a continuum of potential adoption opportunities. In the symmetric equilibrium, individual adoption outcomes aggregate to deterministic origin–destination stocks. Let $A_{in,t}$ denote the stock of technologies invented in country n that have been adopted for use in country i by date t. This is the production-relevant adoption stock.

Adoption is costly and uncertain. Adopters in country i invest $H^A_{in,t}$ units of final output to adopt technologies invented in country n. The probability that an unadopted technology from n is successfully implemented in i is

$$\epsilon_{in,t} = \bar{\epsilon}_{in} \left(\frac{H^A_{in,t}}{\bar{Y}_t} \right)^{\beta^A}, \tag{15}$$

where $\bar{\epsilon}_{in}$ is the adoption productivity parameter and $\beta^A \in (0, 1)$ captures diminishing returns to adoption.

The adoption stock evolves according to

$$\Delta A_{in,t} = \epsilon_{in,t} \left(Z_{n,t} - A_{in,t} \right), \tag{16}$$

where $Z_{n,t} - A_{in,t}$ is the mass of technologies invented in n that have not yet been adopted in i. Equivalently, $\epsilon_{in,t}$ is the fraction of the remaining unadopted stock that is implemented in period t.

The production-relevant technology stock in country i is the sum of all technologies adopted for use in country i:

$$T_{i,t} = \sum_{n=1}^{M} A_{in,t}. \tag{17}$$

Technology Licensing. Upon successful adoption, the adopter uses the technology to produce a differentiated intermediate good and pays the innovator for the right to use it. We model licensing as a fixed-rate profit-sharing contract. For technologies invented in country n and adopted in country i at date t, the adopter pays the innovator a royalty share $\eta_{in,t}$ of flow profits $\pi_{in,t}$. The royalty share is determined when the contract is signed and remains fixed for that adoption cohort. Thus, all technologies from the same origin–destination pair adopted at date t face the same royalty share $\eta_{in,t}$ for as long as their licensing relationships remain compliant.

In the symmetric equilibrium, individual licensing outcomes aggregate to deterministic origin–destination royalty-paying stocks. Let $A^L_{in,t}$ denote the subset of technologies invented in n, adopted for use in i, and still associated with compliant royalty-paying licensing relationships at date t. Newly adopted technologies enter this stock when their licensing contracts are signed. Existing royalty-paying relationships remain compliant between t and $t+1$ with probability $1-\phi_{in,t+1}$, where

$$\phi_{in,t+1} \equiv \phi\left(d^P_{in,t+1}, \mathrm{IPR}_i\right) \tag{18}$$

is the probability that a royalty-paying licensing relationship becomes non-compliant. Hence,

$$A^L_{in,t+1} = \left(A_{in,t+1} - A_{in,t}\right) + \left(1-\phi_{in,t+1}\right) A^L_{in,t}. \tag{19}$$

A non-compliant relationship no longer generates royalty payments, but the technology remains in production. Thus, $A_{in,t}$ governs production and remaining adoption opportunities, while $A^L_{in,t}$ governs royalty payments.

Because contracts are signed when technologies are adopted, different adoption cohorts may carry different royalty shares. Let $A^L_{in,t}(\tau)$ denote the mass of technologies invented in n, adopted in i at date $\tau \leq t$, and still compliant at date t. Define the average royalty claim on the production-relevant adoption stock as

$$\mathcal{L}_{in,t} \equiv \frac{1}{A_{in,t}} \sum_{\tau \leq t} \eta_{in,\tau} A^L_{in,t}(\tau). \tag{20}$$

This object is the royalty claim per unit of the total adopted stock $A_{in,t}$, not the average royalty share among compliant technologies only. The normalization is useful because all adopted technologies enter production, including those that no longer generate royalty payments.

The royalty share $\eta_{in,t}$ is determined by Nash bargaining at date t, given the economic and enforcement conditions prevailing at that date.[2] The bargaining problem is

$$\eta_{in,t} \in \arg\max_{\eta} \left(V^{\mathrm{Innov}}_{in,t}(\eta)\right)^{\rho_{in}} \left(V^{\mathrm{Adopt}}_{in,t}(\eta)\right)^{1-\rho_{in}}, \tag{21}$$

[2] This follows the idea in Benhabib, Perla, and Tonetti (2017).

where ρ_{in} is the innovator's bargaining power, and $V_{in,t}^{\text{Innov}}$ and $V_{in,t}^{\text{Adopt}}$ denote the continuation values to the innovator and adopter from licensing a newly adopted technology at date t.[3]

Geopolitical tensions affect the bargaining problem through enforcement risk. We assume $\partial\phi/\partial d_{in,t}^{P} > 0$ and $\partial\phi/\partial \text{IPR}_i < 0$: greater geopolitical distance raises the probability of non-compliance, whereas stronger IPR protection lowers it. The enforcement risk relevant for bargaining at date t is the one anticipated under date-t conditions. It affects the continuation values in equation (21) and therefore the royalty share negotiated for the new cohort. Once the contract is signed, however, the royalty share for that cohort is fixed. Later changes in geopolitical conditions affect future contracts, but not the royalty shares on existing ones.

For a newly negotiated contract at date t, the innovator's value satisfies

$$\begin{aligned} V_{in,t}^{\text{Innov}} &= \eta_{in,t}\pi_{in,t} + \frac{P_{n,t}}{R_t P_{n,t+1}} \left(1-\phi_{in,t}\right) V_{in,t+1}^{\text{Innov}} \\ &= \eta_{in,t}\,\Upsilon_{in,t}, \end{aligned} \tag{22}$$

where $\Upsilon_{in,t}$ is the discounted value of the compliant profit stream associated with the newly signed contract.

The adopter's value when the contract remains compliant is

$$\begin{aligned} V_{in,t}^{\text{Adopt}} &= (1-\eta_{in,t})\pi_{in,t} + \frac{P_{i,t}}{R_t P_{i,t+1}} \left[\left(1-\phi_{in,t}\right) V_{in,t+1}^{\text{Adopt}} + \phi_{in,t} V_{in,t+1}^{\text{Breach}}\right] \\ &= \left(1-\eta_{in,t}\right)\Upsilon_{in,t} + \Upsilon_{in,t}^{\text{Breach}}, \end{aligned} \tag{23}$$

where $\Upsilon_{in,t}^{\text{Breach}}$ denotes the continuation value associated with non-compliance. If non-compliance occurs, the adopter keeps using the technology and receives the full profit flow:

$$V_{in,t}^{\text{Breach}} = \pi_{in,t} + \frac{P_{i,t}}{R_t P_{i,t+1}} V_{in,t+1}^{\text{Breach}}. \tag{24}$$

Both $\Upsilon_{in,t}$ and $\Upsilon_{in,t}^{\text{Breach}}$ are determined by the profit stream $\pi_{in,t}$ and the enforcement hazard faced by the newly negotiated contract. These objects summarize the conditions under which the date-t contract is signed.

[3] In the symmetric equilibrium, all technologies from origin n adopted in destination i at date t face the same royalty share $\eta_{in,t}$.

Royalty Fee. Solving the Nash bargaining problem in equation (21) yields

$$\eta_{in,t} = \rho_{in}\left[1 + \frac{\Upsilon^{\text{Breach}}_{in,t}}{\Upsilon_{in,t}}\right]. \tag{25}$$

The royalty share consists of the standard Nash-bargaining component and an additional term that compensates the innovator for the adopter's breach option. A higher breach probability raises the value of this option and therefore increases the royalty share negotiated for technologies licensed at date t. Importantly, this repricing applies only to newly negotiated contracts. Existing contracts continue to pay the royalty share fixed at the time they were signed, so aggregate royalty payments reflect both current royalty rates on new technologies and the inherited royalty shares of older contract vintages.

Royalty Payments. Royalty payments are generated only by adopted technologies whose licensing contracts remain compliant. Because royalty rates are fixed at the time of adoption, aggregate royalty payments depend on both current royalty rates and the surviving stock of older contract vintages.

The vintage representation of the average royalty claim is

$$\begin{aligned}\mathcal{L}_{in,t} \equiv \frac{1}{A_{in,t}}\Bigg[&\eta_{in,t}\big(A_{in,t} - A_{in,t-1}\big) \\ &+ \sum_{s=1}^{t-1}\eta_{in,t-s}\prod_{k=1}^{s}\big(1 - \phi_{in,t-k+1}\big)\big(A_{in,t-s} - A_{in,t-s-1}\big) \\ &+ \eta_{in,0}\prod_{k=1}^{t}\big(1 - \phi_{in,t-k+1}\big)A^{L}_{in,0}\Bigg].\end{aligned} \tag{26}$$

The first term is the royalty claim on the newly adopted cohort. The second term is the surviving royalty claim on older adoption cohorts, whose contracts were negotiated under past royalty rates. The third term is the surviving royalty claim on the pre-existing compliant stock.

Aggregate royalty payments from destination country i to innovators in origin country n are

$$RP_{in,t} = \mathcal{L}_{in,t}A_{in,t}\pi_{in,t}. \tag{27}$$

Equivalently, if $\Pi_{i,t} = T_{i,t}\pi_{i,t}$ denotes aggregate intermediate-good profits in country i and technologies used in i earn common flow profits, then

$$RP_{in,t} = \mathcal{L}_{in,t}\left(\frac{A_{in,t}}{T_{i,t}}\right)\Pi_{i,t}. \tag{28}$$

The average royalty claim evolves recursively according to

$$\mathcal{L}_{in,t+1} = \eta_{in,t}\frac{A_{in,t+1} - A_{in,t}}{A_{in,t+1}} + \mathcal{L}_{in,t}\left(1 - \phi_{in,t+1}\right)\frac{A_{in,t}}{A_{in,t+1}}. \tag{29}$$

The first term is the royalty claim on the newly adopted cohort, which is initially compliant and pays the current royalty rate $\eta_{in,t}$. The second term is the surviving royalty claim on older cohorts, scaled by contract survival and by the share of the current adopted stock inherited from the past.

This recursive representation separates the production-relevant adoption stock $A_{in,t}$ from the royalty-paying component embedded in $\mathcal{L}_{in,t}$. An increase in geopolitical distance raises royalty rates on newly negotiated contracts immediately, but aggregate royalty payments adjust gradually because older contract vintages survive until breach. Thus, royalty payments respond through both a price margin, captured by $\eta_{in,t}$, and a compliant-quantity margin, captured by the survival of legal claims in $\mathcal{L}_{in,t}$.

3.7 Optimal Innovation and Adoption

Before an invention is adopted, its value to the innovator is

$$J^{\text{Innov}}_{in,t} = \frac{1}{R_t}\frac{P_{i,t}}{P_{i,t+1}}\left[\epsilon_{in,t}V^{\text{Innov}}_{in,t+1} + \left(1 - \epsilon_{in,t}\right)J^{\text{Innov}}_{in,t+1}\right]. \tag{30}$$

With probability $\epsilon_{in,t}$, the invention is adopted next period and gives value $V^{\text{Innov}}_{in,t+1}$. With probability $1 - \epsilon_{in,t}$, it remains unadopted and gives continuation value $J^{\text{Innov}}_{in,t+1}$.

The value of an unadopted invention to an adopter is

$$J^{\text{Adopt}}_{in,t} = -P_{i,t}h^{A}_{in,t} + \frac{1}{R_t}\frac{P_{i,t}}{P_{i,t+1}}\left[\epsilon_{in,t}V^{\text{Adopt}}_{in,t+1} + \left(1 - \epsilon_{in,t}\right)J^{\text{Adopt}}_{in,t+1}\right], \tag{31}$$

where $h^{A}_{in,t}$ is the investment required to adopt one technology.

Summing equation (30) across adopting countries gives the total value of an innovation invented in country n:

$$V_{n,t} = \sum_{i=1}^{M} J_{in,t}^{\text{Innov}}. \tag{32}$$

In a symmetric equilibrium, every technology generates the same value and aggregation leads to the first-order conditions for innovation and adoption. The first-order condition for optimal innovation is

$$P_{n,t} H_{n,t}^{R} = \beta^{R} \left(Z_{n,t+1} - Z_{n,t} \right) V_{n,t}. \tag{33}$$

Using equation (31), the first-order condition for optimal adoption is

$$P_{i,t} h_{in,t}^{A} = \beta^{A} \epsilon_{in,t} \frac{P_{i,t}}{R_t P_{i,t+1}} \left(V_{in,t+1}^{\text{Adopt}} - J_{in,t+1}^{\text{Adopt}} \right). \tag{34}$$

Total adoption expenditure is

$$H_{in,t}^{A} = h_{in,t}^{A} \left(Z_{n,t} - A_{in,t-1} \right). \tag{35}$$

3.8 Market Clearing Conditions

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

$$Y_{n,t} = C_{n,t} + H_{n,t}^{R} + \sum_{i=1}^{M} H_{ni,t}^{A}. \tag{36}$$

Labor is supplied inelastically and used for intermediate-good production. Labor-market clearing in country n implies

$$L_{n,t} = \sum_{i=1}^{M} T_{n,t} \frac{x_{in,t} d_{in,t}}{\Omega_{n,t}}, \tag{37}$$

$$\frac{\sigma}{\sigma - 1} W_{n,t} L_{n,t} = \sum_{i=1}^{M} s_{in,t} P_{i,t} Y_{i,t}. \tag{38}$$

Balance of payments requires that net export value equals net royalty payments:

$$\sum_{i \neq n} \frac{s_{in,t} P_{i,t} Y_{i,t}}{1+\tau_{in,t}} + \sum_{i \neq n} RP_{ni,t} = \sum_{i \neq n} \frac{s_{ni,t} P_{n,t} Y_{n,t}}{1+\tau_{ni,t}} + \sum_{i \neq n} RP_{in,t}. \tag{39}$$

The left-hand side collects country n's goods-export revenues and royalty receipts from foreign destinations. The right-hand side collects country n's goods-import payments and royalty payments to foreign innovators.

3.9 Equilibrium

Given the initial vector $\{A_{in,0}, A^L_{in,0}, \mathcal{L}_{in,0}, Z_{n,0}\}$, an equilibrium is a sequence of aggregate prices and wages $\{P_{n,t}, W_{n,t}, R_t\}_{t=0}^{\infty}$, intermediate-good prices and royalty rates $\{p_{in,t}, \eta_{in,t}\}_{t=0}^{\infty}$, value functions $\{\mathcal{V}_t\}_{t=0}^{\infty}$, where

$$\mathcal{V}_t \equiv \left\{ V^{\text{Adopt}}_{in,t}, V^{\text{Innov}}_{in,t}, V^{\text{Breach}}_{in,t}, J^{\text{Adopt}}_{in,t}, J^{\text{Innov}}_{in,t}, V_{n,t} \right\},$$

profits and allocations $\{\Pi_{n,t}, RP_{in,t}, Y_{n,t}, H^R_{n,t}, H^A_{in,t}, s_{in,t}\}_{t=0}^{\infty}$, and technology stocks $\{A_{in,t+1}, A^L_{in,t+1}, \mathcal{L}_{in,t+1}, Z_{n,t+1}\}_{t=0}^{\infty}$ such that:

(i) $\{A_{in,t+1}, A^L_{in,t+1}, \mathcal{L}_{in,t+1}, Z_{n,t+1}\}_{t=0}^{\infty}$ satisfy equations (16), (19), (29), and (12);

(ii) Given prices, household allocations maximize utility in equation (3) subject to the budget constraint in equation (4);

(iii) Given prices, final-good producers solve their problem, yielding equation (6);

(iv) Given prices, intermediate-good producers solve equation (9) subject to demand in equation (6);

(v) Given prices, innovators and adopters solve their problems, consistent with equations (33) and (34);

(vi) Royalty rates are determined by Nash bargaining in equation (21);

(vii) The feasibility condition in equation (36) is satisfied;

(viii) Prices clear all markets in equations (37), (38), and (39).

3.10 Balanced Growth Path

We define the balanced growth path (BGP) as an equilibrium in which aggregate variables grow at a common constant rate and relative objects are stationary. Throughout this section, hats denote stationarized variables and stars denote their stationary BGP values. The BGP is characterized by a stationary vector of relative technology stocks $\{\hat{T}_n^*\}$ and a common growth rate g^*. The pair $(g^*, \{\hat{T}_n^*\})$ solves

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

Equivalently,

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

where $\Delta(g^*)$ collects adoption intensities and innovation productivity evaluated at the stationary allocation. Given the stationary allocation, $\Delta(g^*)$ is nonnegative. Under indecomposability, the Perron–Frobenius theorem implies a unique positive dominant eigenvalue and an associated positive eigenvector.

This representation highlights the two objects that determine long-run technology diffusion and growth. Adoption intensities ϵ_{in}^* govern how quickly technologies diffuse across countries, while innovation effort H_n^{R*} governs how quickly new technologies are created. The next section studies how geopolitical fragmentation affects these margins through market size, contractual enforcement, and the pricing of technology licenses.

4 Mechanisms

This section uses the model to clarify how geopolitical fragmentation affects technology licensing, innovation, and growth. We first study equilibrium objects along the balanced growth path, where relative technology stocks, adoption intensities, royalty rates, and R&D allocations are stationary. We then use a two-country version of the model to illustrate the general-equilibrium forces that are not analytically signed in general. Finally, we return to transition dynamics, where licensing relationships formed under different geopolitical conditions coexist and aggregate repricing is gradual.

There are two channels. The first is a market-size channel: higher trade frictions reduce adopter profits and shrink the scale over which technologies can be profitably adopted and licensed. The second is a contractual-enforcement channel: higher geopolitical risk raises the probability that a licensing relationship becomes non-compliant and induces royalty repricing. These channels affect different margins of the model and need not move innovation in the same direction.

4.1 Royalty Pricing and Contract Repricing

We begin with the pricing of licensing contracts. Along the BGP, a newly negotiated contract between an innovator in country n and an adopter in country i has royalty share

$$\eta_{in} = \rho \frac{1 - \beta_G(1 - \phi_{in})}{1 - \beta_G}, \tag{40}$$

where $\beta_G \equiv \beta/(1+g)$ is the growth-adjusted discount factor.

Proposition 1 (Contract repricing under geopolitical risk)**.** *Along the balanced growth path, newly negotiated licensing contracts reprice in response to enforcement risk:*

$$\frac{\partial \eta_{in}}{\partial \phi_{in}} > 0.$$

Consequently, conditional on IPR protection, higher geopolitical distance raises royalty rates in newly negotiated licensing relationships.

Proof. Differentiating (40) with respect to ϕ_{in} yields

$$\frac{\partial \eta_{in}}{\partial \phi_{in}} = \rho \frac{\beta_G}{1 - \beta_G} > 0,$$

since $\rho \in (0, 1)$ and $\beta_G \in (0, 1)$. □

The proposition isolates the contract-repricing force. Higher geopolitical risk reduces expected enforceability, so newly negotiated contracts compensate the innovator with a higher royalty share. This price response is distinct from technology diffusion. Royalty payments combine the royalty share with the mass of relationships that remain compliant. Along the BGP,

$$RP_{in} = \eta_{in} \frac{A_{in}}{T_i} \bar{m} \frac{g}{g + \phi_{in}}, \tag{41}$$

where $\bar{m} \equiv 1/(\sigma - 1)$. Equation (41) shows why observed royalty flows are not a direct measure of technology diffusion. Higher enforcement risk raises the price of licensing through η_{in}, but it also reduces the expected duration of royalty-paying relationships through $g/(g + \phi_{in})$. Thus, geopolitical fragmentation can increase royalty rates while reducing compliant technology use.

4.2 Surplus Splitting

Contract repricing has a useful implication for surplus division. Although enforcement risk changes the royalty rate, it does not change the division of contractual surplus conditional on successful adoption along the BGP.

Proposition 2 (Balanced-growth surplus allocation)**.** *Along the balanced growth path,*

$$v_{in}^{I} = \rho\, v_{in}^{B}, \tag{42}$$

$$v_{in}^{A} = (1 - \rho)\, v_{in}^{B}. \tag{43}$$

Hence, conditional on successful adoption, equilibrium surplus shares are independent of breach risk.

Proof. Using (40) in the innovator value function,

$$v_{in}^{I} = \eta_{in} \frac{\bar{m} w_i L_i}{1 - \beta_G (1 - \phi_{in})}.$$

Substitution yields

$$v_{in}^{I} = \rho \frac{\bar{m} w_i L_i}{1 - \beta_G} = \rho v_{in}^{B}.$$

The adopter value follows analogously. □

Proposition 2 shows that, on the BGP, royalty repricing offsets the direct effect of enforcement risk on the contractual surplus split. This does not imply that enforcement risk is irrelevant for innovation. Rather, its effects operate through equilibrium changes in adoption, market size, wages, and technology allocations. This distinction separates the pricing of a contract from the general-equilibrium environment in which adoption and innovation decisions are made.

4.3 Innovation Reallocation and Long-Run Growth

We now turn from individual licensing contracts to innovation incentives. The value of an innovation developed in country n aggregates the value of having that innovation adopted across destination markets:

$$v_n^I = \sum_i \frac{T_n}{T_i} j_{in}^I \tag{44}$$

$$= \sum_i \frac{T_n}{T_i} \frac{\beta_G \epsilon_{in}}{1 - \beta_G(1 - \epsilon_{in})} v_{in}^I \tag{45}$$

$$= \sum_i \frac{T_n}{T_i} \frac{\beta_G \epsilon_{in}}{1 - \beta_G(1 - \epsilon_{in})} \eta_{in} \frac{\bar{m} w_i L_i}{1 - \beta_G(1 - \phi_{in})}. \tag{46}$$

Equation (46) identifies the margins through which geopolitical conditions affect innovation values. A single geopolitical shock can move these objects in opposing directions. Higher enforcement risk raises royalty rates through repricing, but may reduce compliant licensing relationships and adoption incentives. Higher trade frictions reduce destination profits and the market available to foreign technologies. Because these margins adjust jointly in general equilibrium, the sign of the innovation response is not analytically determined in general.

We therefore use a two-country economy to illustrate the equilibrium forces. This exercise is not a separate model; it is a restriction of the multi-country environment that makes the mechanisms easier to see. Countries are identical except for innovation productivity and institutional quality: country 1 has higher innovation productivity, $\lambda_1 > \lambda_2$, and stronger intellectual property protection, $\text{IPR}_1 > \text{IPR}_2$. Country 1 is the technological leader and country 2 is the follower. The key adoption margin is ϵ_{21}, adoption in country 2 of technologies developed in country 1, which captures the foreign market available to frontier technologies.

Figure 1 isolates contract repricing by comparing an increase in breach risk under endogenous royalty rates with a counterfactual in which royalty rates are fixed.

Under endogenous repricing, higher breach risk reallocates innovation toward the technological leader: country 1's R&D rises while country 2's R&D falls, and relative wages, technology stocks, and innovation stocks increase. When royalty rates are fixed, innovators cannot adjust contract terms in response to higher enforcement risk, and the same shock has different implications for growth and the allocation of

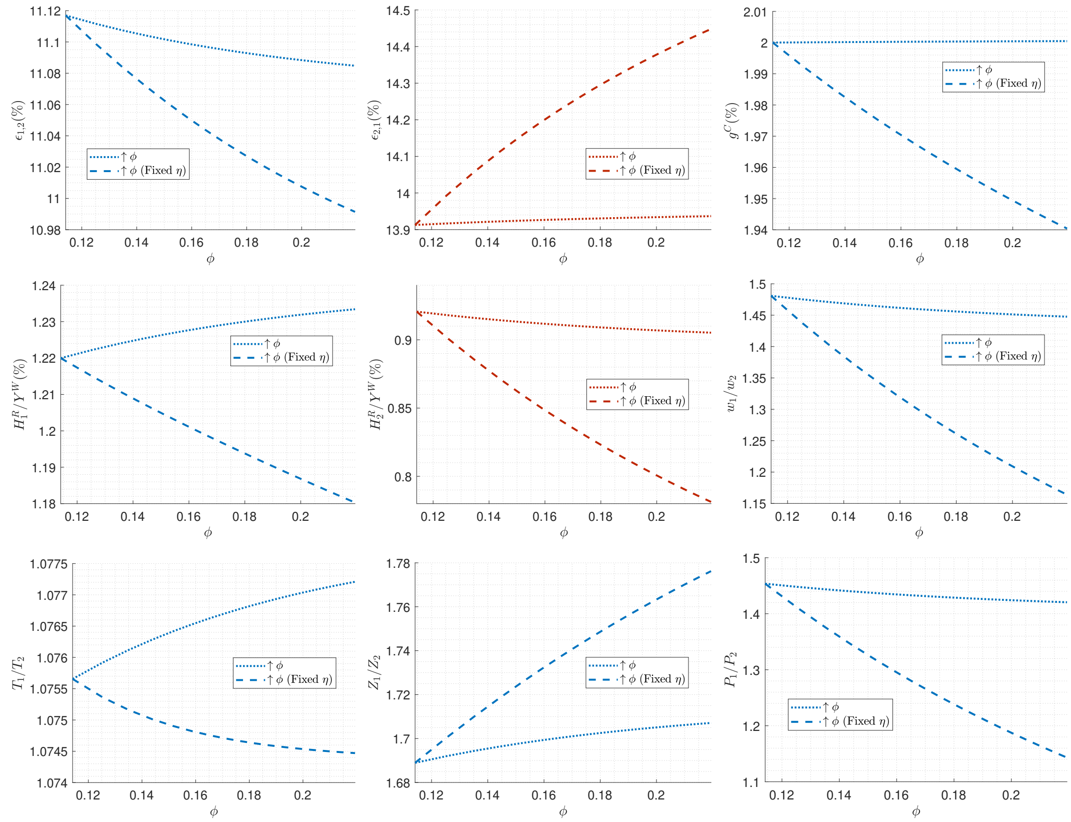


Figure 1: Higher breach risk with endogenous royalty repricing and fixed royalty rates.

innovation. The comparison shows that royalty repricing is part of the economic mechanism, not only an accounting adjustment.

Figure 2 compares the market-size and enforcement channels directly by contrasting an increase in the market-size friction d with an increase in enforcement risk ϕ.

The market-size channel reduces the profitability of adoption in country 2, shrinking the foreign market for country 1's technologies. As a result, H_1^R/Y^w declines, H_2^R/Y^w rises, T_1/T_2 declines, and Z_1/Z_2 declines. Growth falls because innovation shifts away from the more productive innovator. The enforcement channel generates the opposite reallocation: with endogenous repricing, higher enforcement risk shifts innovation toward the technological leader and raises relative wages, technology stocks, and innovation stocks.

Remark 1 (The enforcement channel under alternative royalty payment schedules)**.**

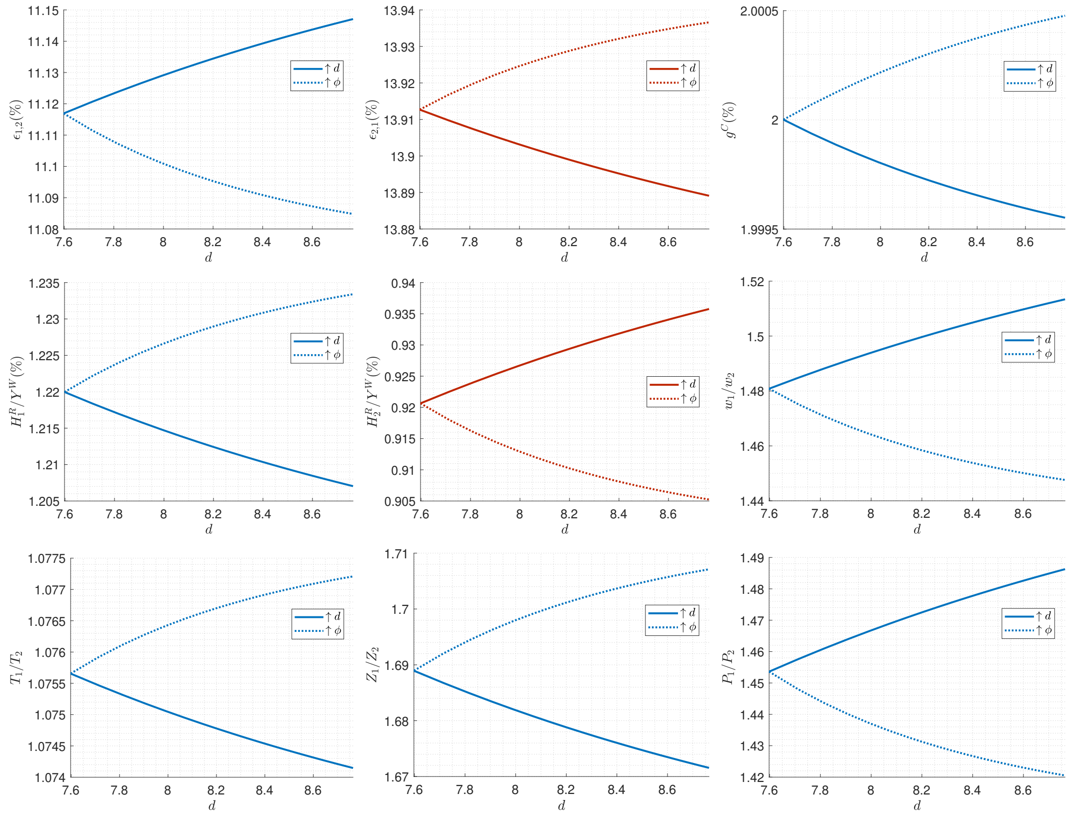


Figure 2: Market-size and breach channels in the two-country economy.

The opposite-sign responses in Figure 2 are specific to the contracting structure of the model. A model with fixed licensing terms or no contractual enforcement friction cannot generate a reallocation of R&D toward the leader through enforcement risk alone; higher enforcement risk would reduce innovation returns through the quantity margin. Endogenous repricing therefore changes not only the magnitude but also the direction of the enforcement channel. Whether the enforcement or market-size channel dominates in the calibrated economy is a quantitative question addressed in Section 5.

Along the BGP, global growth is

$$g = \sum_{n=1}^{M} \lambda_n (h_n^R)^{\beta^R}. \tag{47}$$

Differentiating with respect to a geopolitical parameter x gives

$$\frac{\partial g}{\partial x} = \beta^R \sum_{n=1}^{M} \lambda_n (h_n^R)^{\beta^R - 1} \frac{\partial h_n^R}{\partial x}. \tag{48}$$

The growth effect depends on how geopolitical fragmentation reallocates equilibrium R&D across countries. Growth rises when R&D moves toward locations with sufficiently high marginal innovation productivity and falls when R&D moves away from those locations. In the calibrated economy studied below, the R&D response is market-size dominant: fragmentation lowers frontier R&D and reduces the BGP growth rate.

4.4 Transition Dynamics and Contract Vintages

The preceding results describe stationary allocations. Along a BGP, all active licensing relationships are governed by the same stationary environment: newly negotiated contracts and surviving contracts face the same enforcement risk and the same royalty schedule. In that case, repricing is complete. This is why Propositions 1 and 2 imply that enforcement risk affects royalty rates but does not directly alter the contractual surplus split conditional on successful adoption.

A transition after a geopolitical shock has an additional state variable: the vintage composition of licensing relationships. New adoption cohorts are priced under the new geopolitical environment, while older cohorts remain governed by royalty shares negotiated before the shock until those relationships become non-compliant. Aggregate royalty claims therefore adjust more slowly than newly negotiated royalty rates. This matters for innovation because firms choose R&D based on the value of a new blueprint, which depends on future adoption, profits, and royalty payments. Even when new contracts reprice immediately, the aggregate state variables that shape adoption and innovation incentives inherit past contractual conditions.

This gradual adjustment is captured by the law of motion for the compliant stock, derived in Section 3:

$$A_{in,t+1}^L = (A_{in,t+1} - A_{in,t}) + (1 - \phi_{in,t+1})\, A_{in,t}^L.$$

The first term is the new adoption cohort, whose contracts are negotiated under current conditions. The second term is the surviving stock of older compliant relationships, whose royalty shares were set when those cohorts were adopted.

The same vintage logic applies to the average royalty claim $\mathcal{L}_{in,t}$. Its law of motion is

$$\mathcal{L}_{in,t+1} = \eta_{in,t} \frac{A_{in,t+1} - A_{in,t}}{A_{in,t+1}} + \mathcal{L}_{in,t} \left(1 - \phi_{in,t+1}\right) \frac{A_{in,t}}{A_{in,t+1}}.$$

The first term applies the royalty share negotiated for the current adoption cohort. The second term carries forward surviving claims from earlier cohorts, weighted by contract survival and by the inherited share of the adoption stock. Thus, $\eta_{in,t}$ can jump with the shock, whereas $\mathcal{L}_{in,t}$ adjusts gradually.

This vintage structure implies a gap between newly negotiated royalty terms and the average royalty claim embedded in the aggregate state. After a permanent geopolitical shock, newly formed licensing relationships are priced under the new enforcement environment. Existing compliant relationships, however, continue to reflect the terms negotiated when those cohorts were adopted, as long as they remain compliant. As a result, the average royalty claim $\mathcal{L}_{in,t}$ need not jump one-for-one with the royalty share on new contracts, $\eta_{in,t}$.

The speed of adjustment depends on the composition of active relationships. When new adoption accounts for a large share of the active stock, the average claim moves quickly toward the terms faced by newly negotiated contracts. When instead most active relationships are inherited from the past, and when those relationships remain compliant for longer, past contractual terms continue to matter for aggregate royalty claims. In this sense, contract vintages make the transition more gradual than the adjustment of newly negotiated royalty rates alone.

This mechanism links the stationary analysis to the quantitative transition exercise. The BGP characterizes the allocation once all active relationships are priced under common stationary conditions. During the transition, aggregate royalty claims reflect both newly repriced contracts and surviving contract vintages. The quantitative model evaluates how this gradual repricing interacts with adoption, wages, technology stocks, R&D, growth, and welfare during the adjustment.

5 Quantitative Analysis

We now use the quantitative model to study how geopolitical fragmentation affects trade, technology diffusion, innovation, growth, and welfare. This exercise is needed for two reasons. First, the theoretical results identify the main forces in the model, but their aggregate importance is ambiguous because the enforcement and market-size channels push innovation incentives in different directions. Second, geopolitical shocks unfold along transition paths. During the transition, new licensing relationships are priced under the new geopolitical environment, while older relationships continue to reflect the terms negotiated before the shock as long as they remain compliant. As a result, aggregate royalty claims, adoption, and innovation incentives adjust gradually rather than jumping immediately to their new balanced-growth values.

The counterfactual exercises therefore serve two purposes. First, they trace the dynamic effects of geopolitical fragmentation on trade, royalty flows, innovation, growth, and welfare. Second, the decompositions in the Appendix isolate the enforcement and market-size channels by shutting down each in turn, allowing us to quantify their relative contributions to innovation reallocation and welfare effects. The quantitative analysis complements the analytical results by measuring the strength of the mechanisms and their interaction along the transition.

We calibrate the model to bilateral trade flows, royalty payments, R&D intensities, patent stocks, citation flows, and standard gravity variables across eight regions over 2000–2020, treating this period as the pre-fragmentation calibration window. We then study a counterfactual increase in US–China geopolitical rivalry beginning in 2021, so that post-2020 dynamics are generated by the model rather than used to discipline the pre-shock calibration. The analysis traces the implications for trade, technology adoption, innovation, growth, and welfare. Welfare is measured in consumption-equivalent units.

We then apply our theory to study export controls as restrictions on international technology adoption. We first consider a government that maximizes household consumption and then extend the analysis to allow governments to value technological leadership in addition to consumption. The algorithm used to solve for the balanced growth path and transition dynamics is described in the Appendix.

5.1 Calibration

The calibration disciplines the quantitative model with three sets of moments: (i) directly observed country-level aggregates, (ii) gravity-based estimates of trade and technology-diffusion frictions, and (iii) moments governing innovation, licensing, and transition dynamics. Table 2 reports the common calibrated parameters, while Table 3 reports the region-specific objects. The mapping between parameters, initial states, and targeted moments is summarized in Table 4. The main paper reports the objects needed to understand the quantitative exercises and the link between the theory and the calibrated economy. The Appendix provides the full parameter mapping, bilateral matrices, and estimation details.

Directly observed objects. We use national accounts and the World Development Indicators to measure GDP, population, expenditure shares, labor endowments, and R&D expenditures. Patent stocks are constructed using a perpetual-inventory method with a depreciation rate of 15 percent. Geographical distance comes from CEPII, while geopolitical distance is measured using ideal-point distances in United Nations voting. The elasticity of substitution across varieties, the discount factor, and the bargaining parameter are set to values standard in the quantitative trade and growth literature; these common parameters are reported in Table 2. Labor endowments, productivity, innovation efficiency, and IPR enforcement vary across regions and are reported in Table 3.

Trade, technology diffusion, and breach risk. Bilateral trade frictions are disciplined using structural gravity. In particular, trade shares identify bilateral iceberg costs of the form

$$d_{in} = (d_{in}^G)^{\kappa^G} (d_{in}^P)^{\kappa^P}, \tag{49}$$

where d_{in}^G denotes geographical distance and d_{in}^P denotes geopolitical distance. The estimated trade-politics elasticity, κ^P, governs the strength of the market-size channel and is reported in Table 2.

Technology diffusion is disciplined using bilateral patent citation flows from INPACT-S. The fitted bilateral component of a citation gravity equation is mapped into adoption intensities ϵ_{in}, which determine the probability that country i adopts technologies developed in country n. These adoption probabilities are the key objects governing the effective foreign market for licensable technologies.

Breach risk is parameterized as

$$\phi_{in}(d_{in}^P, \xi_n) = (1-\xi_n)\left[1-\exp\left(1-(d_{in}^P)^{\kappa^\phi}\right)\right], \tag{50}$$

where ξ_n captures IPR enforcement in the adopter country. Geopolitical distance raises breach risk, while stronger IPR enforcement lowers the maximum attainable breach probability. The enforcement parameters ξ_n are reported in Table 3, and the elasticity κ^ϕ, which governs the strength of the breach channel, is reported in Table 2.

Innovation and licensing. Innovation parameters are disciplined using R&D expenditures, patent stocks, and growth moments. Country-specific innovation efficiency λ_n governs how R&D effort translates into new technologies and is reported in Table 3, while the curvature parameter β^R and innovation scale γ are reported in Table 2. The remaining parameters and initial states are chosen to match bilateral technology flows, royalty payment shares, and transition dynamics, as summarized in Table 4.

Parameter	Description	Value
β	Discount factor	0.96
β^A	Adoption curvature	0.3843
β^R	Innovation curvature	0.3843
σ	Elasticity of substitution	5
ρ	Innovator bargaining weight	0.25
κ^G	Trade-geography elasticity	1
κ^P	Trade-politics elasticity	0.1030
κ^ϕ	Breach-politics elasticity	0.0923
γ	Innovation scale	1.6227

Table 2: Common calibrated parameters.

Targeted moments and fit. The calibration targets moments that discipline the model's main mechanisms: trade shares and productivity for the market-size channel, citation flows for adoption, R&D and patent stocks for innovation, and royalty flows for the licensing channel. Table 4 summarizes the mapping between parameters and targeted moments.

Table 3: Region-specific calibrated parameters

Parameter	Description	USA	CAN	MEX	EU	CHN	JPN	KOR	ROW
λ_i	Innov. eff.	0.1634	0.0191	0.0092	0.0518	0.1078	0.0748	0.0318	0.0425
L_i	Labor endowment	1.0000	0.1105	0.3674	1.6440	4.3432	0.4128	0.1607	6.5303
Ω_i	Productivity	0.6219	0.5121	0.3708	0.4570	0.3405	0.5609	0.4628	0.2942
ξ_i	IPR enforcement	0.9432	0.9709	0.4535	0.7358	0.1597	0.8686	0.8268	0.5368

Parameter or state	Targeted moment
Ω_n	Total factor productivity
$\bar{\epsilon}_{in}$	Average adoption efficiency
λ_n	R&D expenditure shares and patenting
γ	Long-run growth rate
κ^{ϕ}	Royalty response to geopolitical distance
$A_{in,0}$	Transitional growth rates
$\mathcal{L}_{in,0}$	Royalty payment shares

Table 4: Parameters, initial states, and targeted moments.

The calibrated values of κ^P and κ^{ϕ}, reported in Table 2, are central for interpreting the mechanism decomposition. The trade-politics elasticity is slightly larger than the breach-politics elasticity ($\kappa^P = 0.1030$ versus $\kappa^{\phi} = 0.0923$), placing the calibrated economy on the side where market-size effects dominate breach effects.

As external validation, the calibrated model reproduces several untargeted moments closely: the correlation between model-implied and empirical TFP levels is 0.983, and the correlation for bilateral adoption probabilities is 0.996. The model also matches cross-country R&D intensities and bilateral royalty payment shares reasonably well. The Appendix reports the full bilateral trade-cost matrices, adoption matrices, model-versus-data fit tables, and a qualitative royalty-regression validation. Because the quantitative model aggregates countries into eight regions, the model-implied royalty regression is not intended to reproduce the country-level elasticities one-for-one. Instead, the exercise asks whether the calibrated mechanism generates the same qualitative relationship between geopolitical distance, enforcement quality, and royalty flows.

5.2 Counterfactual: Bilateral US–China Fragmentation

We now study the counterfactual in which geopolitical distance between the United States and China rises permanently.[4] Figure 3 reports the transition dynamics for adoption, royalty rates, R&D effort, and bilateral royalty payments following the shock.

The main effect of fragmentation is a decline in cross-border technology adoption together with endogenous contract repricing. Higher geopolitical distance raises breach risk and lowers the expected continuation value of international licensing relationships. At the same time, fragmentation reduces the effective market size over which technologies can be profitably licensed by lowering trade integration and shrinking the scale of foreign adoption. These two forces jointly reduce the value of exporting frontier technologies internationally.

As shown in Figure 3, China's adoption of US technologies declines persistently relative to baseline. Royalty rates nevertheless increase through Nash bargaining as innovators demand compensation for higher enforcement risk. Fragmentation therefore generates a price–quantity wedge in technology flows: contractual prices rise, but the quantity of technology diffusion falls. Quantitatively, the decline in adoption dominates, causing aggregate royalty payments to fall over time despite higher royalty rates.

Figure 3 also illustrates the repricing gap. The newly negotiated royalty rate $\eta_{in,t}$ responds immediately to the higher breach hazard, while the average legal claim $\mathcal{L}_{in,t}$ adjusts gradually because it embeds surviving contract vintages negotiated before the shock. Thus, royalty payments do not move one-for-one with the new royalty rate: they reflect both current repricing and the slow replacement of inherited licensing relationships. This vintage composition is the reason the transition differs from a direct comparison of the old and new BGPs.

These licensing dynamics feed directly into innovation incentives, as reflected in the R&D panels of Figure 3. In the United States, lower foreign adoption reduces the value of exporting frontier technologies and weakens R&D incentives. In China, reduced access to foreign technologies raises the relative value of domestic innovation and induces substitution toward internal R&D. Geopolitical fragmentation therefore reallocates innovation geographically: research activity shifts toward the follower

[4] The increase in geopolitical distance d^P is calibrated to double breach probability ϕ.

economy while aggregate innovation and growth decline.

The transition also generates asymmetric welfare effects. The reduction in compliant technology diffusion lowers profits and consumption in the United States, while China partially offsets lower foreign adoption through a reallocation of innovation toward domestic R&D activity. At the same time, fragmentation narrows the relative technology gap between the two countries, implying a gradual erosion of US technological leadership.

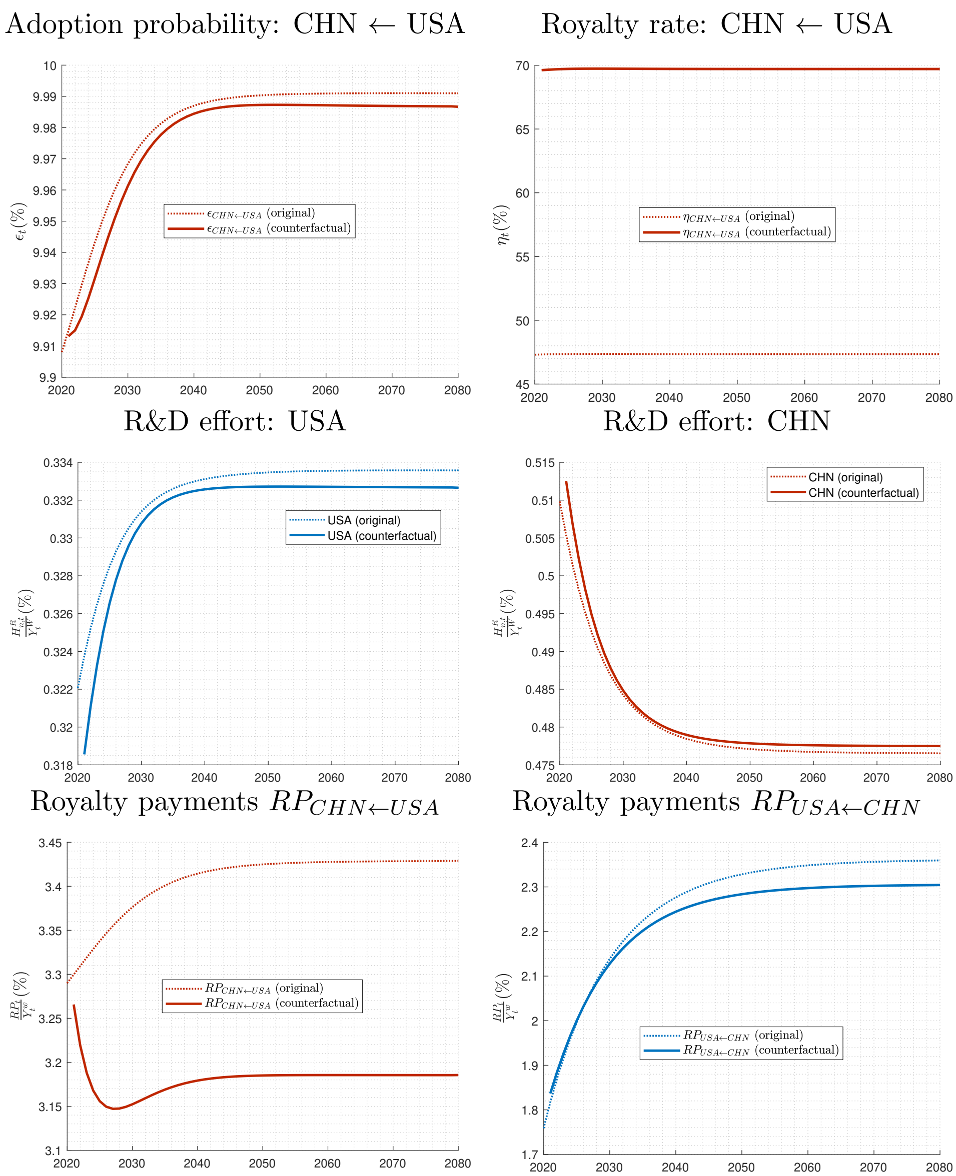
Figure 4 summarizes these welfare-relevant outcomes. Relative technology declines as innovation reallocates toward China, while consumption deviations remain quantitatively modest but persistent.

The counterfactual highlights the interaction between two forces in the model. The first is a bargaining channel through which higher geopolitical distance raises royalty rates by increasing breach risk. The second is a market-size channel through which fragmentation reduces compliant adoption and the scale of international technology diffusion. Quantitatively, the market-size channel dominates, implying lower adoption, weaker frontier innovation, and lower long-run growth despite higher royalty rates.

The decompositions clarify the independent contribution of each channel. When market-size effects are shut down and only breach risk rises, US R&D increases and Chinese R&D falls; the opposite of what the full model and a market-size-only framework predict. The market-size channel dominates in the aggregate calibrated economy, but the breach channel determines the direction of R&D reallocation conditional on enforcement conditions, and generates the welfare asymmetry between the two countries: under breach risk alone, the leader retains a larger share of innovation rents rather than losing them to the follower.

The welfare effects of fragmentation also extend beyond the United States and China. Because innovation and adoption are globally linked, changes in bilateral technology flows reallocate licensing, trade, and innovation activity across third countries. Table 5 reports consumption-equivalent welfare changes under the same increase in geopolitical distance. China experiences welfare gains because a larger share of innovation rents is retained domestically, while the United States experiences welfare losses due to lower foreign adoption and reduced royalty revenues. Most third countries experience small negative welfare effects as global technology diffusion and growth decline.

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 after the shock.



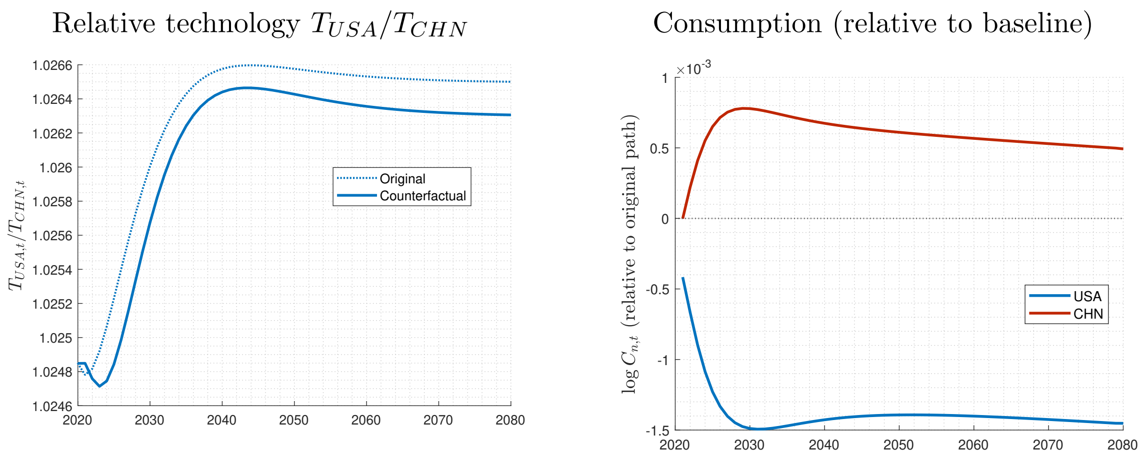


Figure 4: Welfare-relevant outcomes of a permanent increase in US–China geopolitical distance. Relative technology declines as innovation reallocates toward China, while consumption reflects the asymmetric welfare effects of fragmentation.

Table 5: Welfare and Growth Effects of Geopolitical Fragmentation (consumption-equivalent changes, %)

$\%\Delta W_i^{eff}$	US–CHN Rivalry (ϕ double)
USA	-0.133
CAN	-0.010
MEX	-0.006
EU	-0.010
CHN	0.059
JPN	0.001
KOR	-0.002
ROW	-0.008
$\%\Delta g$	-0.017

Notes: The table reports consumption-equivalent welfare changes following an increase in geopolitical distance, calibrated as a doubling of ϕ between the United States and China. Positive values denote welfare or growth gains; negative values denote losses. Growth rates refer to changes in the balanced-growth-path consumption growth rate.

5.3 Policy Application: Export Controls

The counterfactual treats geopolitical fragmentation as an exogenous increase in bilateral geopolitical distance. We now ask whether a government would choose to create a similar restriction through policy. This exercise serves two purposes. First, it distinguishes efficiency motives from strategic motives for restricting technology transfer. Second, it shows that the welfare implications of export controls depend on the same price–quantity wedge and innovation-reallocation forces emphasized above.

We analyze unilateral export controls as restrictions on international technology adoption, modeled as a policy wedge that reduces bilateral adoption intensity:

$$\bar{\epsilon}_{in}^{policy} = (1 - \chi_{in})\,\bar{\epsilon}_{in}, \tag{51}$$

where $\chi_{in} \in [0, 1]$ measures the intensity of export restrictions. The analysis delivers two results. First, export controls are not optimal when governments value only household consumption, because restricting technology diffusion lowers aggregate efficiency without offsetting gains. Second, positive export controls can emerge as optimal when governments value technological leadership in addition to consumption, because restricting foreign access to frontier technologies affects the future allocation of innovation activity across countries. We characterize each case in turn.

Consumption-Based Welfare. Under a pure consumption objective, tighter export controls reduce welfare monotonically. Although royalty rates rise through endogenous contract repricing, the reduction in compliant adoption dominates, compressing the scale over which domestic technologies are used abroad and lowering the balanced-growth-path growth rate. Figures 5 and 6 illustrate these effects. The optimal export control is therefore

$$\chi^* = 0.$$

This result is a direct implication of the market-size channel established in Section 3.10. Export controls act as an additional source of market-size contraction, reducing the effective scale of international technology diffusion beyond what geopolitical fragmentation already generates. A government that internalizes the gains from technology diffusion therefore has no incentive to impose further restrictions.

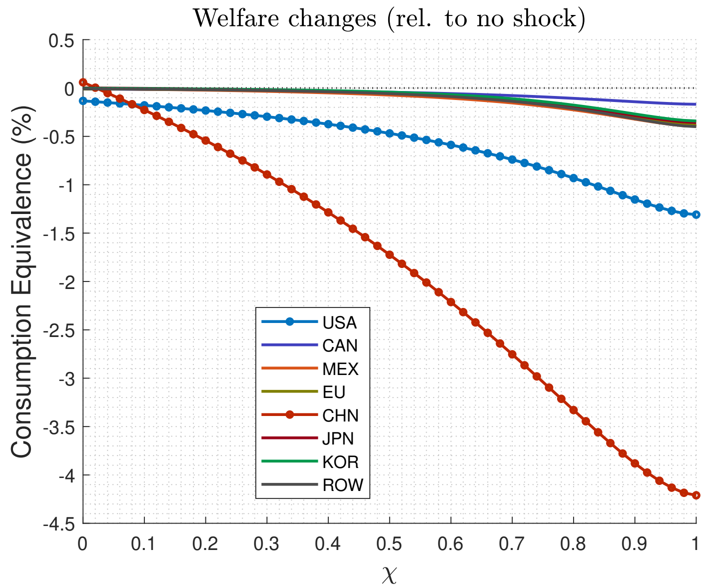


Figure 5: Consumption-equivalent welfare effects of export controls.

Notes: Each line reports the consumption-equivalent welfare change for a given region relative to the no-controls baseline. Higher χ denotes tighter U.S. export restrictions on China. Welfare declines monotonically for all regions as export controls tighten.

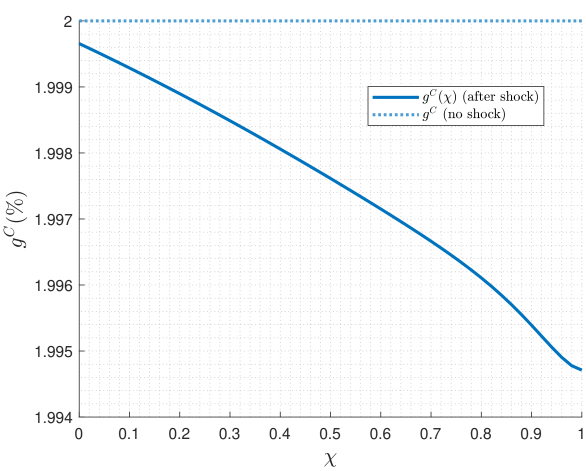


Figure 6: Export controls and the balanced-growth-path growth rate.

Notes: The solid line reports the balanced-growth-path growth rate $g^*(\chi)$ as export-control intensity χ increases. The dotted line reports the growth rate in the no-shock baseline. Tighter export controls lower the effective scale of international technology diffusion and reduce long-run growth monotonically.

This benchmark clarifies the role of the contracting channel in the policy analysis. Export controls reduce adoption directly through the quantity margin, that is, the same margin through which the market-size channel operates. Endogenous royalty repricing partially offsets the welfare cost of reduced adoption by reallocating some surplus to innovators, but this offset does not reverse the aggregate efficiency loss. Thus, the model does not provide an efficiency rationale for export controls. It provides a strategic rationale: restrictions can be optimal only when the planner values the future allocation of innovation activity, not merely current consumption.

Strategic Objectives and Optimal Export Controls. We therefore extend the government's objective to allow for strategic considerations:

$$W_n = \sum_{t=0}^{\infty} \beta^t \left[\log C_{n,t} + \omega \mathcal{S}_{n,t}\right], \tag{52}$$

where $\mathcal{S}_{n,t}$ captures the value of technological leadership and $\omega \geq 0$ governs the weight placed on strategic considerations relative to consumption. When $\omega = 0$, equation (52) reduces to the consumption-based objective and the result above applies. When $\omega > 0$, the government places direct value on the relative technology stock $T_{n,t}/T_{-n,t}$, creating an incentive to restrict foreign access to frontier technologies.

Under a government objective that depends only on household consumption ($\omega = 0$), the numerically optimal unilateral export control is $\chi^* = 0$. When the government values technological leadership ($\omega > 0$), positive export controls can arise in the calibrated equilibrium. In the numerical exercises below, the optimal export-control intensity $\chi^*(\omega)$ is increasing in ω and satisfies $\chi^*(0) = 0$.

The key mechanism is that export controls affect not only current consumption and technology diffusion, but also the future distribution of technological leadership. By restricting foreign access to frontier technologies, a government slows the technological catch-up of rival economies, shifting the long-run allocation of innovation activity in its favor. This future benefit is absent from the consumption-based objective and therefore generates no intervention under $\omega = 0$.

Figure 7 reports the optimal export-control intensity χ^* as a function of ω under three retaliation scenarios. In the no-retaliation case, positive controls emerge at relatively low values of ω because the strategic benefit of slowing foreign catch-up is not offset by bilateral losses. Uncertainty about retaliation raises the threshold value of ω at which intervention becomes optimal. When retaliation is certain, positive controls arise only for sufficiently high ω because bilateral restrictions compress both countries' access to foreign technologies symmetrically, reducing the net strategic gain.

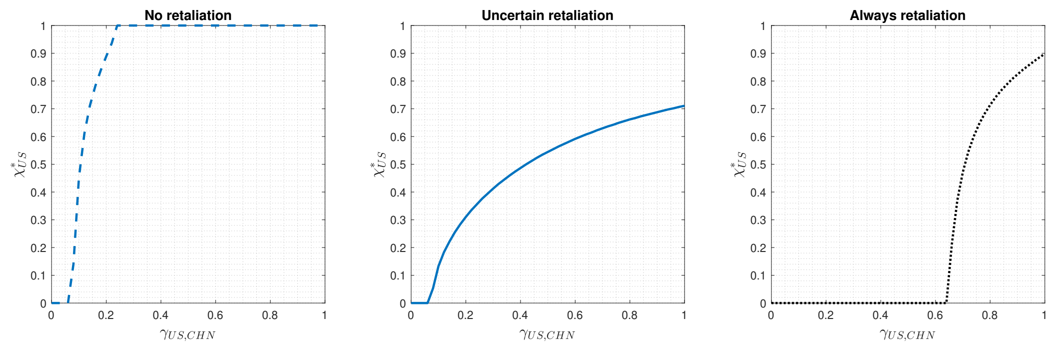


Figure 7: Optimal export-control intensity and strategic concerns.

Notes: Each panel reports the optimal export-control intensity χ^* as a function of the strategic weight ω in the government objective (52). Left panel: no retaliation by China. Center panel: uncertain retaliation. Right panel: certain retaliation. The optimal control is zero at $\omega = 0$ in all cases and increasing in ω, with the threshold depending on the retaliation environment.

The export-control exercise reinforces the main mechanism of the paper. Because technology transfer is mediated by licensing contracts, restricting foreign adoption affects both current royalty revenues and the future geography of innovation. The same contracting channel that shapes the response to geopolitical shocks also determines whether policy restrictions can shift technological leadership. Without strategic preferences, this channel is not enough to justify intervention; with strategic preferences, it changes the policy tradeoff.

Two broader implications follow from this analysis. First, export controls in this model are not a response to market failures or contracting inefficiencies. Private licensing arrangements are constrained efficient given geopolitical frictions, and there is no role for intervention on contracting grounds alone. Export controls emerge solely from government preferences that extend beyond aggregate consumption to include relative technological standing. Second, because export controls are costly, as they reduce technology diffusion, lower global innovation incentives, and decrease the balanced-growth-path growth rate for all countries, the relevant policy question is whether alternative instruments can achieve the same strategic objectives at lower efficiency cost. The model suggests that domestic R&D subsidies targeted at frontier innovation could raise a country's relative technology stock without compressing the bilateral adoption margin, potentially dominating export controls on both efficiency and strategic grounds. A full characterization of the optimal policy mix between export controls and domestic innovation subsidies is left to future work.

6 Final Remarks

This paper studies how geopolitical shocks reshape innovation through the contractual structure of cross-border technology adoption. Many forms of diffusion occur outside formal licensing, but licensing is the margin where prices are explicitly set and innovation rents are allocated. Recent policy interventions such as export controls, licensing restrictions, and investment screening, operate directly on these contractual margins, and the data show that royalty flows are more sensitive than goods trade to geopolitical distance, especially where enforcement is weak. This makes licensing a natural laboratory for studying how political risk feeds back into innovation incentives.

Our quantitative results show that fragmentation reallocates innovation across countries and lowers BGP growth rates by compressing compliant adoption. The same price–quantity mechanism governs the welfare consequences of policy interventions. Under a pure consumption objective there is no role for export controls; intervention arises only when governments value technological leadership in addition to efficiency.

A central finding is that the breach and market-size channels move innovation in opposite directions, so their interaction determines both the sign and distribution of R&D reallocation across countries. Models that omit the contracting channel, treating licensing terms as fixed or abstracting from enforcement frictions, predict that fragmentation uniformly suppresses frontier innovation. The present framework shows that this prediction holds only when market-size forces dominate; when breach forces dominate, fragmentation can raise innovation effort in the leader and generate gains for the country initiating restrictions. Understanding which regime applies requires quantifying both channels jointly, as we do here.

More broadly, when innovation is traded through enforceable contracts, geopolitical frictions propagate through pricing and adoption decisions rather than through trade volumes alone. Understanding global growth under fragmentation therefore requires tracking how political risk reshapes the market for technology itself.

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Appendix

A 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 *tradeflow_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 Airaudo et al. (2025), which estimates IPD using the full sample of UN votes; *ipd_econ_full* from Airaudo 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 range from 2000 to 2021.

Table A.1 reports descriptive statistics for the variables of interest for the period 2007-2021 when the sample is restricted to 43 countries.

Table A.1: Descriptive Statistics of Key Variables

	mean	sd	min	p25	p50	p75	max	count
IPR Index	0.70	0.18	0.00	0.55	0.69	0.89	1.00	27,090
Log Geopolitical Distance	-1.06	1.46	-12.76	-1.85	-0.86	0.14	1.33	27,090
Royalties (Mill. USD)	183.22	1045.71	0.00	0.56	5.43	46.49	56376.05	27,090
Trade Flow (Mill. USD)	7170.37	27800.00	0.00	116.11	769.05	3896.19	775000.00	27,090

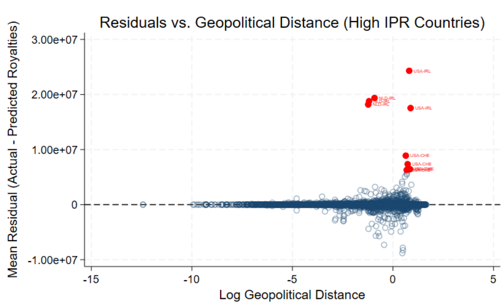
Country-Pairs Driving the Positive Geopolitical Coefficient A natural concern is that the positive coefficient on geopolitical distance is driven by tax havens that attract royalty payments for fiscal rather than technological reasons. To address this issue, we re-estimate the specification excluding common royalty-routing destinations such as Ireland, the Netherlands, and Switzerland. The coefficient on geopolitical distance falls substantially, although it remains positive and statistically significant.

Table A.2: List of Countries

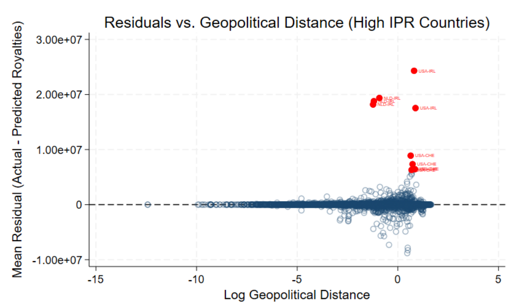
ISO	Country	ISO	Country	ISO	Country
AUS	Australia	AUT	Austria	BEL	Belgium
BGR	Bulgaria	BRA	Brazil	CAN	Canada
CHE	Switzerland	CHN	China	CYP	Cyprus
CZE	Czech Republic	DEU	Germany	DNK	Denmark
ESP	Spain	EST	Estonia	FIN	Finland
FRA	France	GBR	Great Britain	GRC	Greece
HRV	Croatia	HUN	Hungary	IDN	Indonesia
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
VNM	Vietnam				

Examining the residuals from the restricted regression shows that the largest positive outliers correspond primarily to flows between technologically advanced economies, especially the United States, the European Union, and Japan. These country-pairs exhibit royalty flows that are systematically larger than predicted by geopolitical distance alone. This suggests that, once tax-haven effects are removed, the remaining positive association partly reflects intense licensing relationships among innovation leaders with strong IPR protection.

Figure A.1 illustrates these patterns. The left panel shows residuals after excluding tax havens, where advanced-economy pairs remain the dominant positive outliers. The right panel highlights the importance of royalty-routing hubs such as Ireland and Switzerland in the unrestricted specification.



Excluding tax havens



Baseline residuals

Figure A.1: Residuals and geopolitical distance

Overall, the results suggest that the baseline positive relationship between geopolitical distance and royalties is partly driven by a small number of country-pairs with exceptional institutional or fiscal characteristics.

B 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:

$$\hat{C}_{n,t} = \hat{Y}_{n,t} - \hat{H}^R_{n,t} - \hat{H}^A_{n,t} \tag{B1}$$

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

Price indices:

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

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

Trade shares (This is stationary without normalization):

$$s_{in,t} = \frac{\Omega^{\sigma-1}_{nt} \hat{T}_{n,t} (\bar{m}\hat{\omega}_{n,t} d_{in}(1+\tau_{in,t}))^{1-\sigma}}{\hat{P}^{1-\sigma}_{i,t}}, \tag{B2}$$

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:

$$\hat{V}_{n,t} \equiv \sum_{i=1}^{M} \hat{J}^{innov}_{in,t} \frac{\hat{T}_{n,t}}{\hat{T}_{i,t}} \tag{B3}$$

Profits of all firms:

$$\hat{\Pi}_{n,t} \equiv \frac{\Pi_{n,t}}{W_{M,t}} = \bar{m}\hat{\omega}_{n,t} L_n \tag{B4}$$

The value of contract breach:

$$\hat{V}^{Breach}_{in,t} = \bar{m}\hat{\omega}_{i,t} L_i + \frac{\hat{V}^{Breach}_{in,t+1}}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \frac{(1+g_{M,t})^{\frac{1}{\sigma-1}}}{1+g^T_{i,t}} \tag{B5}$$

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:

$$\hat{V}_{in,t}^{Innov} = \eta_{in} \bar{m} \hat{\omega}_{i,t} L_i + (1 - \phi(d_{in}^P)) \frac{\hat{V}_{in,t+1}^{Innov}}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \tag{B6}$$

The value of adopted innovation to adopter:

$$\hat{V}_{in,t}^{Adopt} = (1 - \eta_{in}) \bar{m} \hat{\omega}_{i,t} L_i + \frac{(1 - \phi(d_{in}^P)) \hat{V}_{in,t+1}^{Adopt} + \phi(d_{in}^P) \hat{V}_{in,t+1}^{Breach}}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \tag{B7}$$

The value of unadopted innovation to inventor:

$$\hat{J}_{in,t}^{Innov} = \frac{1}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \left[\epsilon_{in,t} \hat{V}_{in,t+1}^{Innov} + (1 - \epsilon_{in,t}) \hat{J}_{in,t+1}^{Innov} \right] \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \tag{B8}$$

The value of unadopted innovation to adopter:

$$\hat{J}_{in,t}^{Adopt} = \frac{1}{R_t} \frac{\hat{P}_{i,t}}{\hat{P}_{i,t+1}} \left[(1 - \beta_a) \epsilon_{in,t} \hat{V}_{in,t+1}^{Adopt} + (1 - \epsilon_{in,t} + \beta_a \epsilon_{in,t}) \hat{J}_{in,t+1}^{Adopt} \right] \frac{(1 + g_{M,t})^{\frac{1}{\sigma-1}}}{1 + g_{i,t}^T} \tag{B9}$$

C 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.

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

- $\phi_t \in [0, 1]$: Probability that a legitimate technology is imitated after one period
- η_t: Royalty fee applied to legitimate technologies
- π_t: Profit generated by each technology
- T_t: Total number of available technologies in the market

C.1 Evolution of Legitimate Technologies

The stock of legitimate technologies evolves according to:

$$A_t^L = (A_t - A_{t-1}) + (1 - \phi_t) A_{t-1}^L \tag{C1}$$

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

C.2 Royalty Revenue Generation

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

$$RP_t = \eta_t \frac{A_t - A_{t-1}}{T_t} \pi_t + \eta_t (1-\phi_t) A_{t-1}^L / T_t \tag{C2}$$

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
- $\eta_t (1-\phi_t) A_{t-1}^L$: Royalty revenue from previously legitimate technologies that remain protected from imitation

C.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:

$$g_A = \frac{A_t - A_{t-1}}{A_{t-1}} \tag{C3}$$

This implies:

$$A_t = (1+g_A)A_{t-1} \tag{C4}$$

$$A_{t-1} = \frac{A_t}{1+g_A} \tag{C5}$$

For any time period $t-j$:

$$A_{t-j} = \frac{A_t}{(1+g_A)^j} \tag{C6}$$

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

$$\frac{A_t}{T_t} = \alpha \tag{C7}$$

Therefore:

$$T_t = \frac{A_t}{\alpha} \tag{C8}$$

$$T_{t-j} = \frac{A_{t-j}}{\alpha} = \frac{A_t}{\alpha(1+g_A)^j} = \frac{T_t}{(1+g_A)^j} \tag{C9}$$

C.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:

$$A_{t-j} - A_{t-j-1} = g_A A_{t-j-1} = \frac{g_A A_t}{(1+g_A)^{j+1}} \tag{C10}$$

Therefore, the stock of legitimate technologies at time t is the sum of all past technology flows, each adjusted by its probability of remaining legitimate:

$$A_t^L = (A_t - A_{t-1}) + (1-\phi)(A_{t-1} - A_{t-2}) + (1-\phi)^2(A_{t-2} - A_{t-3}) + \dots \tag{C11}$$

$$= \sum_{j=0}^{\infty}(1-\phi)^j(A_{t-j} - A_{t-j-1}) \tag{C12}$$

$$= \sum_{j=0}^{\infty}(1-\phi)^j \frac{g_A A_t}{(1+g_A)^{j+1}} \tag{C13}$$

$$= g_A A_t \sum_{j=0}^{\infty} \frac{(1-\phi)^j}{(1+g_A)^{j+1}} \tag{C14}$$

$$= \frac{g_A A_t}{1+g_A} \sum_{j=0}^{\infty} \left(\frac{1-\phi}{1+g_A}\right)^j \tag{C15}$$

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 $\frac{1}{1-r}$:

$$A_t^L = \frac{g_A A_t}{1+g_A} \frac{1}{1-\frac{1-\phi}{1+g_A}} \tag{C16}$$

$$= \frac{g_A A_t}{1+g_A} \frac{1+g_A}{1+g_A-(1-\phi)} \tag{C17}$$

$$= \frac{g_A A_t}{1+g_A} \frac{1+g_A}{\phi+g_A} \tag{C18}$$

$$= \frac{g_A A_t(1+g_A)}{(1+g_A)(\phi+g_A)} \tag{C19}$$

$$= \frac{g_A A_t}{\phi+g_A} \tag{C20}$$

Similarly, for the previous period:

$$A_{t-1}^L = \frac{g_A A_{t-1}}{\phi+g_A} \tag{C21}$$

$$= \frac{g_A \frac{A_t}{1+g_A}}{\phi+g_A} \tag{C22}$$

$$= \frac{g_A A_t}{(\phi+g_A)(1+g_A)} \tag{C23}$$

C.3.2 BGP Royalty Revenue

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

$$\text{Royalty Revenue}_t = \eta \frac{A_t - A_{t-1}}{T_t} \pi + \eta(1-\phi) \frac{A_{t-1}^L}{T_t} \pi \tag{C24}$$

Substituting our expressions:

$$\text{Royalty Revenue}_t = \eta \frac{g_A A_{t-1}}{\frac{A_t}{\alpha}} \pi + \eta(1-\phi) \frac{\frac{g_A A_t}{(\phi+g_A)(1+g_A)}}{\frac{A_t}{\alpha}} \pi \tag{C25}$$

$$= \eta \frac{g_A \frac{A_t}{1+g_A}}{\frac{A_t}{\alpha}} \pi + \eta(1-\phi) \frac{g_A A_t}{(\phi+g_A)(1+g_A)} \frac{\alpha}{A_t} \pi \tag{C26}$$

$$= \eta \frac{g_A \alpha}{1+g_A} \pi + \eta(1-\phi) \frac{g_A \alpha}{(\phi+g_A)(1+g_A)} \pi \tag{C27}$$

Factoring out the common terms:

$$\text{Royalty Revenue}_t = \eta \alpha \pi g_A \left[\frac{1}{1+g_A} + \frac{1-\phi}{(\phi+g_A)(1+g_A)} \right] \tag{C28}$$

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

$$\frac{1}{1+g_A} + \frac{1-\phi}{(\phi+g_A)(1+g_A)} = \frac{\phi+g_A}{(\phi+g_A)(1+g_A)} + \frac{1-\phi}{(\phi+g_A)(1+g_A)} \tag{C29}$$

$$= \frac{\phi+g_A+1-\phi}{(\phi+g_A)(1+g_A)} \tag{C30}$$

$$= \frac{1+g_A}{(\phi+g_A)(1+g_A)} \tag{C31}$$

$$= \frac{1}{\phi+g_A} \tag{C32}$$

Therefore, the royalty revenue simplifies to:

$$\text{Royalty Revenue}_t = \eta\alpha\pi g_A \frac{1}{\phi+g_A} \tag{C33}$$

$$= \eta\alpha\pi \frac{g_A}{\phi+g_A} \tag{C34}$$

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 $\phi \to 0$ (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.

C.3.3 Special Cases

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

$$\text{Royalty Revenue}_t = \eta\alpha\pi \frac{g_A}{0+g_A} = \eta\alpha\pi \tag{C35}$$

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

$$\text{Royalty Revenue}_t = \eta\alpha\pi \frac{g_A}{1+g_A} \tag{C36}$$

D 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 $\{\hat{\omega}_i^*, \eta_{in}^*, \frac{H_{in}^{A*}}{\bar{Y}^*}\}$ to compute prices, trade shares, outputs, and value functions. We solve for the fixed point with three layers of iterations

  (a) iterate adoption rate $\frac{H_{in}^{A*}}{\bar{Y}^*}$ 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 $\frac{H_n^{R*}}{\bar{Y}^*}$ and solve for a new $\{\hat{Z}_n^*, g^*\}$ applying Perron-Frobenius Theorem. Iterate until it converges.

Transitional Dynamics

Assume the economy reaches the BGP at time T. To compute the transition from an arbitrary initial condition $\{Z_{n,0}, A_{in,0}, \mathcal{L}_{in,0}\}$ 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 $\{Z_{n,0}, A_{in,0}, \mathcal{L}_{in,0}\}$, 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.

E Calibration Details

This appendix provides the calibration details underlying the quantitative analysis. The main text reports the objects needed to understand the economic content of the calibration. Here we describe the mapping from data to parameters, the construction of bilateral frictions and adoption intensities, the method-of-moments procedure, and the validation exercises.

E.1 Data and Directly Measured Quantities

The calibration uses data on trade flows, GDP, population, R&D expenditures, patent stocks, royalty payments, patent citations, geographical distance, and geopolitical distance. Country labor endowments L_n, GDP, population, expenditure shares, and R&D expenditures are taken from national accounts and the World Development Indicators. Geographical distance d_{in}^G comes from CEPII. Geopolitical distance d_{in}^P is measured using ideal-point distances based on United Nations voting records.

Patent stocks are constructed using the perpetual inventory method with depreciation rate $\delta_Z = 0.15$. The elasticity of substitution across varieties, σ, the household discount factor, β, and the bargaining parameter, ρ, are set using values standard in the quantitative trade and growth literature. The remaining parameters are disciplined using the structural mappings described below.

E.2 Trade Flows, Trade Costs, and Productivity

Trade flows are taken from the CEPII BACI dataset. Bilateral trade costs are estimated using a structural gravity equation for import shares. Let

$$s_{in,t} = \frac{X_{in,t}}{\sum_m X_{mn,t}},$$

where $X_{in,t}$ denotes exports from country i to country n at time t. We estimate

$$\ln s_{in,t} = \alpha_{i,t} + \delta_{n,t} - \kappa^G \ln d_{in}^G - \kappa^P \ln d_{in}^P + \varepsilon_{in,t}. \tag{E1}$$

Exporter–year fixed effects $\alpha_{i,t}$ and importer–year fixed effects $\delta_{n,t}$ absorb multilateral resistance terms. Estimation is performed using PPML following Yotov et al. (2016).

The estimated elasticities imply bilateral iceberg trade costs

$$d_{in} = (d_{in}^G)^{\kappa^G} (d_{in}^P)^{\kappa^P}. \tag{E2}$$

The model-implied trade share is

$$s_{in,t} = \frac{\Omega_{i,t}^{\sigma-1} T_{i,t} (W_{i,t} \tilde{d}_{in,t})^{1-\sigma}}{\sum_m \Omega_{m,t}^{\sigma-1} T_{m,t} (W_{m,t} \tilde{d}_{mn,t})^{1-\sigma}}. \tag{E3}$$

Comparing equations (E1) and (E3), exporter fixed effects identify

$$\alpha_{i,t} = (\sigma - 1) \log \Omega_{i,t} + \log T_{i,t} + (1 - \sigma) \log W_{i,t} + \text{const.} \tag{E4}$$

Given wages and technology stocks, productivity is backed out as

$$\Omega_{i,t} = \left(\frac{\exp\{\alpha_{i,t}\} W_{i,t}^{\sigma-1}}{T_{i,t}} \right)^{1/(\sigma-1)}. \tag{E5}$$

Table E.1: Estimated Total Trade Costs d_{in}^{total}

Importer \ Exporter	USA	CAN	MEX	EU	CHN	JPN	KOR	ROW
USA	–	6.257	7.779	10.811	7.598	8.813	10.582	15.594
CAN	1.799	–	4.514	5.542	3.845	4.352	5.246	8.306
MEX	3.169	6.426	–	6.874	4.177	5.140	6.182	8.174
EU	3.651	6.190	5.828	–	3.809	4.408	4.763	6.767
CHN	6.219	10.948	8.483	8.878	–	4.847	5.053	10.209
JPN	5.319	9.075	7.438	7.857	3.626	–	4.469	8.902
KOR	4.276	7.348	6.004	6.146	2.515	3.007	–	7.308
ROW	3.082	5.554	3.796	4.053	2.569	3.530	4.052	–

Notes: The table reports bilateral total trade costs, combining geographical and geopolitical components.

Table E.2: TFP and GDP per Capita Relative to the United States

Region	TFP (USA = 1)	GDP per Capita (USA = 1)
USA	1.000	1.000
CAN	0.823	0.724
MEX	0.587	0.152
EU	0.733	0.573
CHN	0.523	0.163
JPN	0.903	0.615
KOR	0.742	0.506
ROW	0.470	0.074

Notes: TFP is backed out from the gravity system and normalized relative to the United States.

E.3 Adoption Probabilities

We discipline bilateral adoption probabilities using international patent citation flows from INPACT-S following Caballero and Jaffe (1993) and Cai, Li, and Santacreu (2022). Citations from country d to patents originating in country o reveal cross-border knowledge diffusion from o to d.

Let C_{odt} denote citation flows from origin country o to destination country d. We estimate the citation gravity equation

$$C_{odt} = \exp\left(\beta_1 \ln \text{dist}_{od} + \beta_2 \text{contig}_{od} + \beta_3 \text{comlang}_{od} + \beta_4 \ln \text{geo}_{od} + \alpha_{o,t} + \delta_{d,t}\right) + \varepsilon_{odt}. \tag{E6}$$

The fitted bilateral component is

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

We map this index into an adoption probability using

$$\widehat{p}_{od}^{\text{adopt}} = \frac{1}{1+\exp(-\widehat{\text{pair}}_{od})}. \tag{E7}$$

Assuming adoption occurs with constant hazard ϵ_{od} over horizon L_{od},

$$p_{od}^{\text{adopt}} = 1 - \exp(-\epsilon_{od} L_{od}), \tag{E8}$$

which implies

$$\widehat{\epsilon}_{od} = -\frac{1}{L_{od}} \log\left(1 - \widehat{p}_{od}^{\text{adopt}}\right). \tag{E9}$$

Table E.3: Estimated Adoption Intensities ϵ_{in}

Adopter \ Innovator	USA	CAN	MEX	EU	CHN	JPN	KOR	ROW
USA	0.333	0.247	0.106	0.140	0.103	0.111	0.114	0.135
CAN	0.247	0.333	0.153	0.188	0.114	0.137	0.138	0.152
MEX	0.107	0.149	0.333	0.134	0.154	0.135	0.133	0.188
EU	0.141	0.188	0.134	0.333	0.127	0.176	0.178	0.157
CHN	0.104	0.114	0.154	0.127	0.333	0.179	0.204	0.166
JPN	0.115	0.139	0.135	0.176	0.179	0.333	0.325	0.138
KOR	0.116	0.139	0.133	0.179	0.204	0.326	0.333	0.141
ROW	0.132	0.150	0.192	0.161	0.159	0.143	0.142	0.333

Notes: Rows denote adopter regions and columns denote innovator regions.

E.4 Innovation

Innovation parameters are disciplined using R&D expenditures and patent stocks. We estimate

$$\frac{\Delta Z_{n,t}}{Z_t^w} = \lambda_n \left(\frac{RD_{n,t}}{\bar{Y}_t}\right)^{\beta^R}, \tag{E10}$$

where λ_n captures innovation efficiency and β^R governs the curvature of the innovation technology.

Patent stocks are initialized using the average patent stock distribution over 1996–2000 and then evolved using the innovation law of motion.

Table E.4: R&D Intensity, Patent Stocks, and Innovation Efficiency

Region	R&D Intensity (%)	World GDP	GDP	Population	Patent Stock	λ_n
USA	3.2	75800	21369	0.330	992708	0.1634
CAN	1.8	75800	1759	0.038	75042	0.0191
MEX	0.3	75800	1238	0.126	2942	0.0092
EU	1.7	75800	19228	0.518	961228	0.0518
CHN	2.3	75800	14889	1.406	105060	0.1078
JPN	3.2	75800	5037	0.126	1016114	0.0748
KOR	4.6	75800	1693	0.052	243966	0.0318
ROW	1.2	75800	10602	2.226	442591	0.0425

E.5 Joint Calibration Procedure

The remaining parameters

$$\Theta = \{\Omega_n, \bar{\epsilon}_{in}, \lambda_n, \gamma, \kappa^{\phi}, A_{in,0}, \mathcal{L}_{in,0}\}$$

are calibrated jointly using a method-of-moments procedure. The targeted moments are summarized in Table E.5.

Table E.5: Parameters, States, and Targeted Moments

Parameter / State	Targeted Moment
Ω_n	Total factor productivity
$\bar{\epsilon}_{in}$	Average adoption efficiency
λ_n	R&D expenditure share
γ	Long-run growth rate
κ^{ϕ}	Royalties on geopolitical distance
$A_{in,0}$	Transitional growth rates
$\mathcal{L}_{in,0}$	Royalty payment shares

Formally, the calibration solves

$$\min_{\Theta} \left\| M^{\text{model}}(\Theta) - M^{\text{data}} \right\|, \tag{E11}$$

where $M^{\text{model}}(\Theta)$ and M^{data} denote the vectors of model-implied and empirical moments.

The calibration proceeds as follows:

(i) Estimate trade-cost elasticities and recover productivity terms from the gravity system.

(ii) Estimate bilateral adoption intensities from citation gravity and map them into hazards using equation (E9).

(iii) Initialize patent stocks and licensing states using pre-sample patent distributions and observed royalty shares.

(iv) Solve for the balanced growth path and transition dynamics.

(v) Update parameters and initial states until the model matches the targeted moments.

(vi) Calibrate κ^{ϕ} by matching the empirical response of royalty payments to geopolitical distance.

E.6 Breach Probabilities

Breach probabilities are parameterized as

$$\phi_{in}(d^P_{in}, \xi_n) = (1 - \xi_n)\phi_0 \left[1 - \exp\left(1 - (d^P_{in})^{\kappa^{\phi}}\right)\right]. \tag{E12}$$

Table E.6: Region-Specific Calibrated Parameters

Parameter	Description	USA	CAN	MEX	EU	CHN	JPN	KOR	ROW
λ_i	Innovation efficiency	0.1634	0.0191	0.0092	0.0518	0.1078	0.0748	0.0318	0.0425
L_i	Labor endowment	1.0000	0.1105	0.3674	1.6440	4.3432	0.4128	0.1607	6.5303
Ω_i	Productivity	0.6219	0.5121	0.3708	0.4570	0.3405	0.5609	0.4628	0.2942
ξ_i	IPR enforcement	0.9432	0.9709	0.4535	0.7358	0.1597	0.8686	0.8268	0.5368

Table E.7: Calibrated Common Parameters

Parameter	Description	Value
β	Discount factor	0.96
β^A	Adoption curvature	0.3843
β^R	Innovation curvature	0.3843
σ	Elasticity of substitution	5
ρ	Innovator bargaining power	0.25
κ^G	Trade-geography elasticity	1
κ^P	Trade-politics elasticity	0.1030
κ^ϕ	Breach-politics elasticity	0.0923
γ	Innovation scale	1.6227

Geopolitical distance affects the slope of breach risk, while IPR enforcement governs the ceiling:

$$\lim_{d_{in}^P \to \infty} \phi_{in}(d_{in}^P, \xi_n) = (1 - \xi_n)\phi_0. \tag{E13}$$

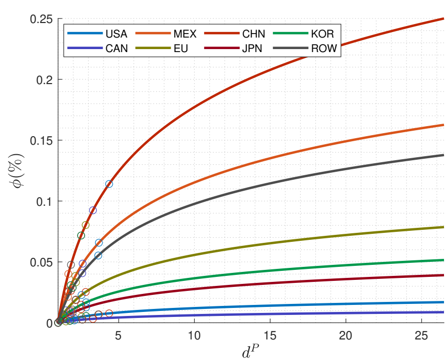


Figure E.1: Breach Hazard as a Function of Geopolitical Distance

Notes: The figure plots equation (E12) for different levels of IPR enforcement.

E.7 Validation Exercises

This subsection reports additional validation exercises not directly targeted in the calibration.

The calibrated model reproduces several untargeted moments. The correlation between model-implied and empirical TFP levels is 0.983, while the correlation for bilateral adoption

Table E.8: Royalty Regressions: Model versus Aggregated Data

	Model	Data
$\log(d^P - 1)$	-0.40503	-0.40502
$\log(d^P - 1)\times$IPR	0.36131	0.91618
$\log(d^G)$	-0.35231	-2.39780

Table E.9: Model Fit: Growth Rates and Royalty Payment Shares

Region	GDP growth rates (%)		Royalty payment shares	
	Model	Data	Model	Data
USA	2.537	2.557	0.143	0.168
CAN	2.594	2.597	0.018	0.044
MEX	1.229	1.235	0.024	0.018
EU	1.815	1.756	0.271	0.300
CHN	9.845	9.853	0.205	0.059
JPN	1.129	1.191	0.062	0.075
KOR	5.043	5.046	0.018	0.031
ROW	—	—	0.259	0.305

probabilities is 0.996. The model also closely matches cross-country R&D intensities and bilateral royalty payments.

The interaction between geopolitical distance and IPR enforcement in royalty regressions is not directly targeted in the calibration and therefore provides an additional validation exercise at the same level of aggregation as the quantitative model. The Data column reports the royalty regression after aggregating bilateral flows to the eight-region geography used in the calibration, while the Model column reports the corresponding regression using model-generated royalty flows. Therefore, these estimates are not intended to reproduce the country-level elasticities reported in Section 2.

F Robustness Analysis: Understanding the Mechanisms

In this section, we show the counterfactual paths where (i) η is fixed, (ii) the market size effect is fixed, (iii) the market size effect and η are both fixed.

The three decompositions isolate the contribution of each channel to the full counterfactual. Figure F.1 shuts down endogenous repricing by holding η fixed; without repricing, the breach channel no longer partially offsets market-size forces and innovation losses are substantially larger.

Figure F.1: Baseline versus Fixed η

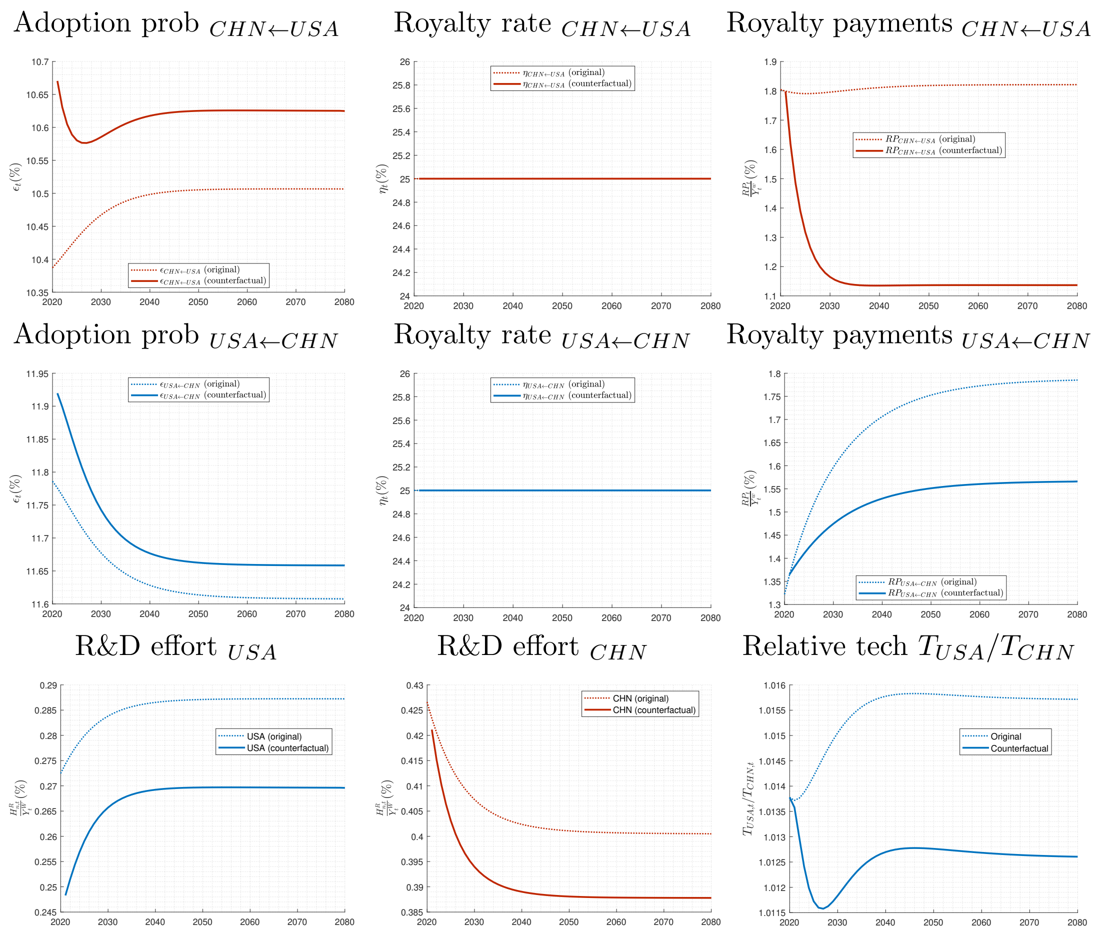


Figure F.2 removes the market-size channel by holding trade costs fixed at baseline; under breach risk alone, US R&D rises and Chinese R&D falls—the opposite direction from the full counterfactual—as innovators capture a larger share of rents through repricing.

Figure F.3 shuts down both channels, providing a pure-breach baseline with fixed royalties; here the adoption decline is driven entirely by enforcement risk without any repricing offset. Together these exercises confirm that the market-size and breach channels operate in opposite directions, and that neither alone replicates the full model's predictions for R&D reallocation or welfare.

Figure F.2: Baseline versus No Market Size Effect

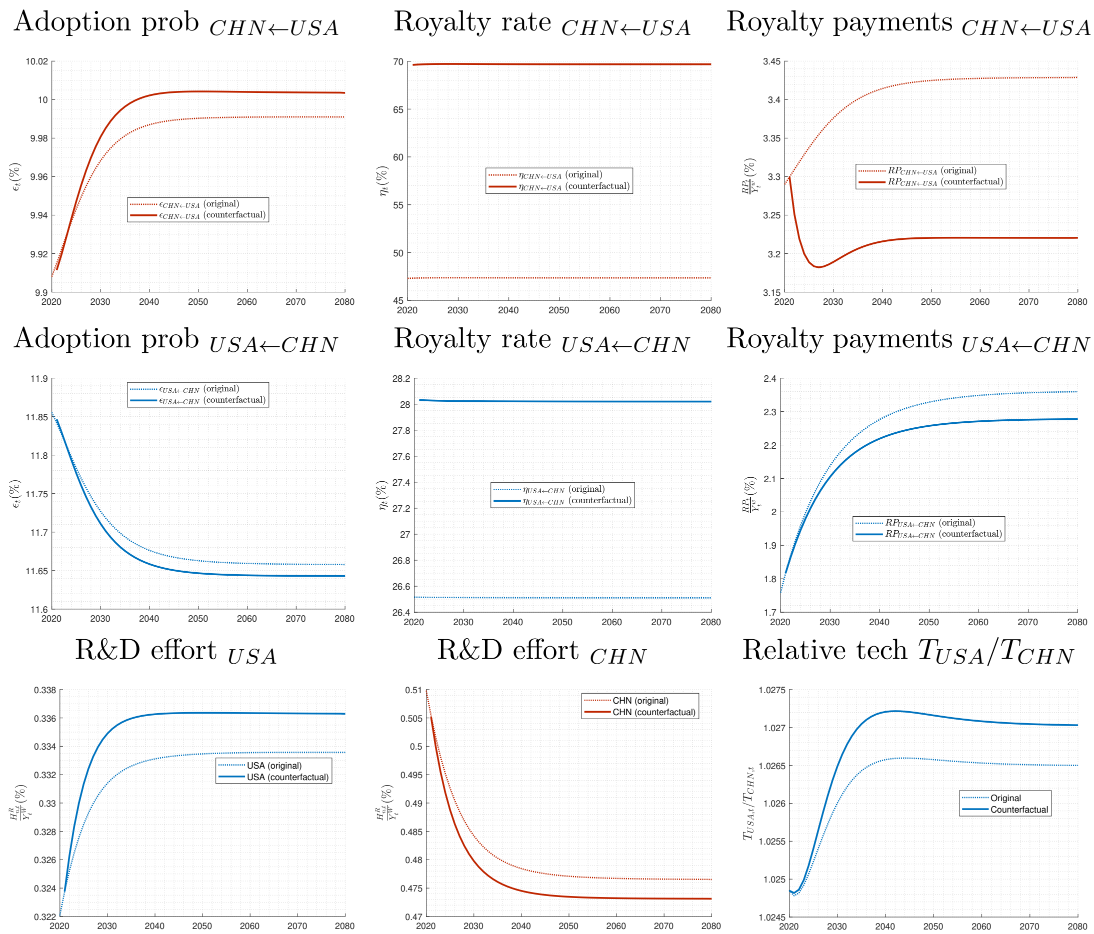


Figure F.3: Baseline versus No Market Size Effect + Fixed η

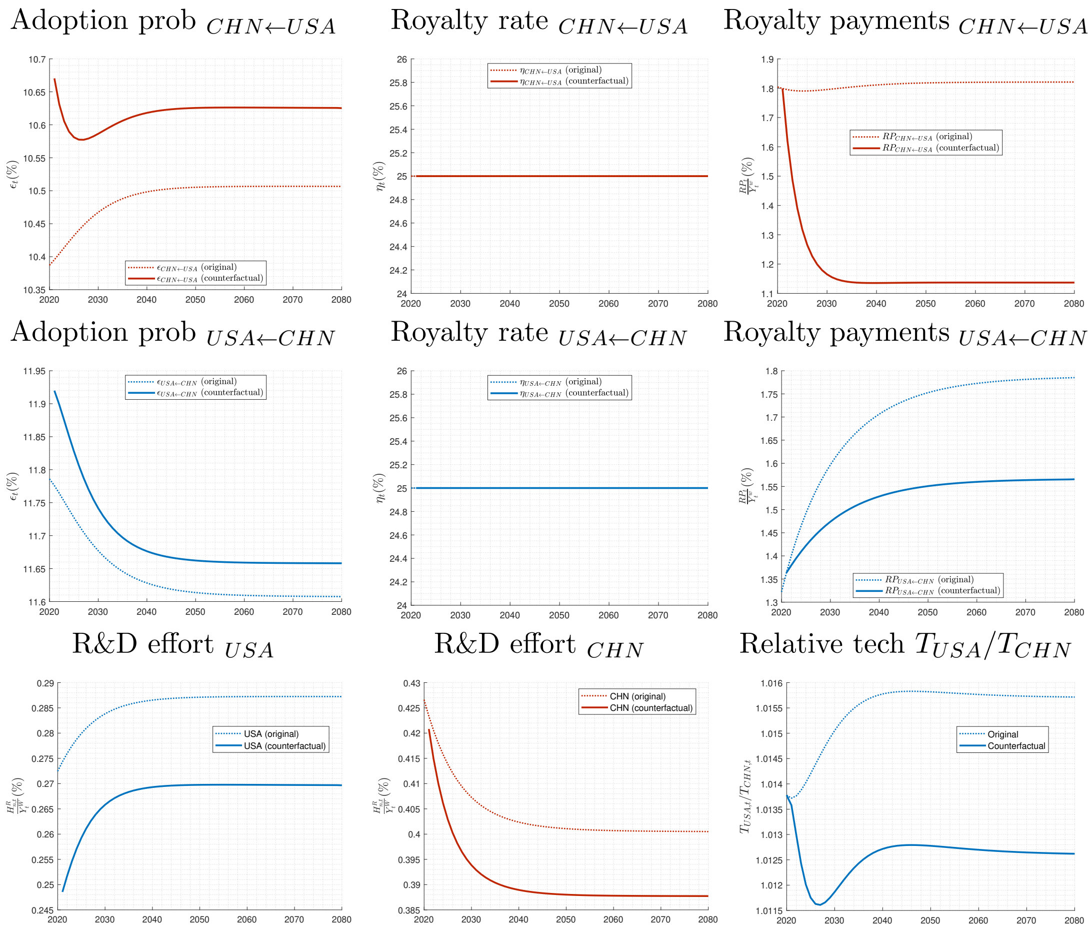
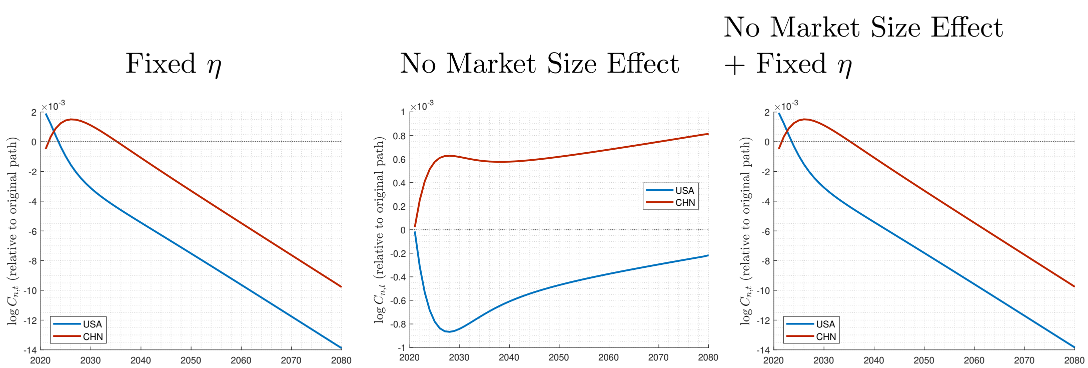


Figure F.4: Counterfactual $\log C_t$ (relative to baseline)



G Mathematical Appendix

This appendix derives the balanced-growth-path relationships that underlie the mechanisms discussed in Section 4. In particular, we show how geopolitical fragmentation affects equilibrium royalty pricing, why surplus shares remain constant along the balanced growth path despite changes in breach risk, and how equilibrium wages and cross-border adoption jointly determine innovation reallocation across countries.

We first derive the equilibrium royalty rate and the surplus-splitting result used in Propositions 1 and 2. We then characterize the joint determination of wages and cross-border technology adoption in the two-country economy used to illustrate the market-size and breach channels.

G.1 Balanced-growth-path royalty pricing and surplus allocation

Along the balanced growth path, all aggregate variables grow at the common rate g. After normalizing by growth, the continuation values of innovators and adopters become stationary. This stationarity allows us to derive closed-form expressions for equilibrium royalty rates and surplus shares.

The key mechanism is straightforward. Higher breach risk shortens the expected duration of licensing relationships. Nash bargaining therefore adjusts royalty rates upward to compensate innovators for the expected loss in future licensing income.

Define the growth-adjusted discount factor as

$$\beta_G \equiv \frac{\beta}{1+g}. \tag{G1}$$

We begin with the value of a breached relationship. Once breach occurs, the adopter keeps the full profit flow forever:

$$v_{in}^B = \frac{\bar{m} w_i L_i}{1-\beta_G}. \tag{G2}$$

The innovator's value under compliance is

$$v_{in}^I = \eta_{in} \frac{\bar{m} w_i L_i}{1-\beta_G(1-\phi_{in})}, \tag{G3}$$

where ϕ_{in} is the probability of contractual breach. The denominator reflects that the licensing relationship survives each period with probability $1-\phi_{in}$.

The adopter's value contains two components: (i) the compliant surplus received while the contract remains enforceable, and (ii) the continuation value obtained if breach occurs in the future. Hence,

$$
\begin{aligned}
v_{in}^{A} &= \frac{(1-\eta_{in})\bar{m}w_i L_i + \beta_G \phi_{in} v_{in}^{B}}{1-\beta_G(1-\phi_{in})} \\
&= (1-\eta_{in})\frac{\bar{m}w_i L_i}{1-\beta_G(1-\phi_{in})} + \frac{\beta_G \phi_{in}}{1-\beta_G}\frac{\bar{m}w_i L_i}{1-\beta_G(1-\phi_{in})}.
\end{aligned} \tag{G4}
$$

Using the recursive representation of continuation values,

$$V_{in,t}^{I} = \eta_{in,t}\Upsilon_{in,t}, \tag{G5}$$

$$V_{in,t}^{A} = (1-\eta_{in,t})\Upsilon_{in,t} + \Upsilon_{in,t}^{Breach}, \tag{G6}$$

and matching these expressions to the balanced-growth-path values above yields

$$\frac{\Upsilon_{in}^{Breach}}{\Upsilon_{in}} = \frac{\beta_G \phi_{in}}{1-\beta_G}. \tag{G7}$$

Substituting these continuation values into the Nash bargaining problem implies that equilibrium royalty rates satisfy

$$\eta_{in} = \rho \frac{1-\beta_G(1-\phi_{in})}{1-\beta_G}. \tag{G8}$$

Equation (G8) establishes the contract-repricing channel described in Proposition 1. Higher geopolitical risk raises breach probabilities, which shortens the expected duration of licensing relationships and therefore increases the compensation innovators require to license technologies abroad.

Importantly, higher royalty payments do not necessarily imply greater technology diffusion. Royalty flows combine both a pricing margin and a quantity margin. Higher breach risk raises equilibrium royalty rates through contract repricing, while simultaneously reducing compliant technology adoption.

We can also derive the balanced-growth-path surplus allocation directly from the value functions. Substituting the equilibrium royalty rate into the innovator value gives

$$v_{in}^{I} = \rho \frac{\bar{m}w_i L_i}{1-\beta_G} = \rho v_{in}^{B}. \tag{G9}$$

Similarly,

$$v_{in}^{A} = (1-\rho)\frac{\bar{m}w_i L_i}{1-\beta_G} = (1-\rho) v_{in}^{B}. \tag{G10}$$

Hence, conditional on successful adoption, equilibrium surplus shares remain constant along the balanced growth path despite changes in breach risk. This result corresponds to Proposition 2 in the main text.

G.2 General-equilibrium determination of wages and technology adoption

Section 4 shows that geopolitical fragmentation affects innovation through two equilibrium objects: (i) cross-border adoption rates and (ii) relative wages.

To illustrate these mechanisms transparently, we study a parsimonious two-country economy in which countries differ only in innovation productivity and institutional quality. In particular, we assume

$$\Omega_1 = \Omega_2, \quad L_1 = L_2, \quad \bar{\epsilon}_{12} = \bar{\epsilon}_{21} = 1, \tag{G11}$$

while

$$\lambda_1 > \lambda_2, \qquad IPR_1 > IPR_2. \tag{G12}$$

Country 1 therefore represents the technological leader, while country 2 represents a follower economy with weaker institutional quality.

Given trade shares, labor-market clearing, and technology accumulation, equilibrium objects such as adoption rates, technology stocks, wages, prices, and output can all be expressed as functions of geopolitical frictions and breach risk.

Three equations are central for equilibrium determination:

(i) two from the adoption block, and

(ii) another one from the balance-of-payments block.

Adoption block The adoption block determines the profitability of cross-border technology diffusion. Higher adoption raises the gains from accessing frontier technologies, but breach risk lowers the expected duration of licensing relationships and therefore reduces the incentive to adopt foreign technologies.

The optimal adoption conditions are

$$(\epsilon_{12})^{\frac{1}{\beta^A}} = \beta^A \beta(1-\rho)\bar{m}\frac{g}{1+g}\frac{A_{12}}{T_1}\frac{1}{P_1 Y^W}\frac{w}{1-\beta_G+\beta_G\epsilon_{12}(1-\beta^A)}, \tag{G13}$$

$$(\epsilon_{21})^{\frac{1}{\beta^A}} = \beta^A \beta(1-\rho)\bar{m}\frac{g}{1+g}\frac{A_{21}}{T_2}\frac{1}{P_2 Y^W}\frac{1}{1-\beta_G+\beta_G\epsilon_{21}(1-\beta^A)}. \tag{G14}$$

These equations characterize how equilibrium adoption responds to changes in relative wages, technology stocks, and geopolitical frictions.

Balance-of-payments block Relative wages are jointly determined by trade balances and royalty flows. The balance-of-payments condition requires

$$NX_{12} = RP_{21} - RP_{12}, \tag{G15}$$

where

$$NX_{12} = (1+\bar{m})\frac{w(1-s_{11})+s_{22}-1}{s_{11}+s_{22}-1}, \tag{G16}$$

$$RP_{21} = \rho\frac{1-\beta_G(1-\phi_{21})}{1-\beta_G}\frac{A_{21}}{T_2}\bar{m}\frac{g}{g+\phi_{21}}, \tag{G17}$$

$$RP_{12} = \rho\frac{1-\beta_G(1-\phi_{12})}{1-\beta_G}\frac{A_{12}}{T_1}\bar{m}w\frac{g}{g+\phi_{12}}. \tag{G18}$$

The balance-of-payments condition links equilibrium wages to technology licensing flows. Changes in geopolitical fragmentation therefore affect wages not only through trade flows, but also through royalty payments and the cross-border allocation of technologies.

To understand the equilibrium mechanisms, it is useful to visualize the joint determination of relative wages and cross-border adoption.

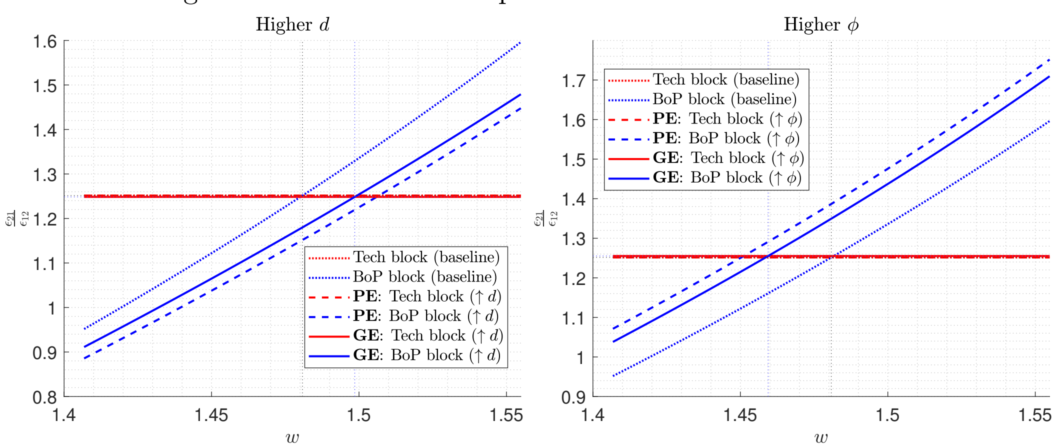


Figure G.1: Relationship between relative wages and cross-border adoption

The equilibrium is determined by the intersection of two schedules: the adoption block and the balance-of-payments block.

The adoption block is downward sloping because higher relative wages reduce the profitability of foreign technology adoption. The balance-of-payments block is upward sloping because countries with higher relative wages require offsetting adjustments in trade balances and royalty flows.

Together, these two relationships determine the equilibrium pair

$$\left\{w, \frac{\epsilon_{21}}{\epsilon_{12}}\right\}, \tag{G19}$$

illustrated in Figure G.1.

The comparative statics map directly into the two mechanisms discussed in the main text.

First, a rise in trade frictions d reduces market size by lowering the profitability of cross-border adoption. This market-size channel reduces the effective foreign market available to frontier technologies and lowers cross-border adoption.

Second, a rise in breach risk ϕ changes the contractual environment governing technology transfer. Through endogenous royalty repricing, the breach channel alters equilibrium wages, adoption incentives, and the allocation of innovation activity across countries.

In partial equilibrium, where g and technology stocks are held fixed, higher trade frictions raise the relative wage and lower the cross-adoption ratio, while higher breach risk lowers the relative wage and raises the cross-adoption ratio.

In general equilibrium, technology stocks and growth respond endogenously, mitigating these effects quantitatively. Nevertheless, the qualitative logic of the market-size and breach channels remains unchanged.