Dynamic Gains from Trade Agreements with Intellectual Property Provisions*

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Abstract

I develop a quantitative theory of bilateral trade agreements with intellectual property (IP) provisions in a multi-country growth model. The model's dynamics are driven by innovation and technology licensing. Imperfect IP enforcement leads to reduced royalty payments and growth. Governments negotiate tariffs and IP enforcement through Nash bargaining. Gains from the trade agreement vary along the transition. Developing countries experience short-term losses, while developed countries gain in both the short and long run. A government with short-term goals may reduce losses but at the cost of lower growth and welfare. Tariffs could discourage developing countries from deviating from the agreement.

Keywords: Technology Licensing; Trade Agreements; Intellectual Property Rights

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1 Introduction

The enforcement and protection of intellectual property rights (IPR) has become an important component of current trade policy. Prior to the formation of the World Trade Organization (WTO) in 1995, regional trade agreements (RTAs) were mostly about removing trade barriers between member countries. The agreement on trade-related aspects of intellectual property rights (TRIPS) that was part of the establishment of the WTO required only minimum standards of IP enforcement. However, recent decades have seen a proliferation of RTAs with IP provisions, and most agreements since 1995 contain such provisions.[1] These are known as deep trade agreements. They require that countries signing the agreement reach IP standards similar to those in developed countries. In return, they offer increased access to international markets. For instance, on January 6, 2003, Chile and the United States signed a trade agreement with high-level IPR protection and enhanced IPR enforcement mechanisms, such as border measures, to prevent entry of products infringing intellectual property (IP) laws.[2] Even in cases in which the countries do not have a formal trade agreement, governments have resorted to trade policy to prevent IP misappropriation. For instance, under Section 301 of the US Trade Act, the United States initiated in 2017 an investigation into China's supposed misappropriation of IPR. The finding of several discriminatory IP-related practices prompted the US administration to impose additional tariffs, ranging from 7.5% to 25%, on approximately $370 billion of US imports from China.[3] More recently, on January 15, 2020, the United States and China signed the first phase of a trade deal in which the United States committed to lower tariffs on Chinese imports in exchange for China, among other things, improving its IP protection. Despite the increasing prevalence of such agreements, existing research has not quantitatively explored the dynamic trade-offs for involved parties.

This paper develops a quantitative theory of bilateral trade agreements with IP provisions to analyze the dynamic trade-offs. The theoretical framework consists of an endogenous growth model of trade in which dynamics are driven by innovation and technology licensing. There is imperfect IP enforcement, which results in reduced royalty payments and lower

[1] See `https://www.stlouisfed.org/on-the-economy/2021/june/intellectual-property-rights-become-key-part-trade-deals`.

[2] In 2007, Costa Rica put to a national referendum a trade agreement that included substantial reductions in tariffs as well as guidelines about IPR (see Van Patten and Méndez, 2022).

[3] `https://crsreports.congress.gov/product/pdf/IF/IF11346`.

growth. Governments engage in Nash bargaining to negotiate over tariffs and the level of IP enforcement. The paper then studies, quantitatively, the short- and long-run implications of the trade agreement on innovation, growth, and welfare.

The paper makes three main contributions. First, it develops a quantitative theory of deep trade agreements that include IP provisions to study their dynamic effects. This bridges the gap between the literature on quantitative dynamic models of trade, innovation and adoption, which traditionally do not include trade agreements, and theoretical political-economy models of trade agreements that frequently do not analyze full dynamics of trade and welfare quantitatively. Second, the paper uses royalty payments data as a measure for technology licensing, shedding light on the impact of IP reforms within the context of deep trade agreements. Third, the paper emphasizes the importance of analyzing the dynamic effects of trade agreements by conducting the analysis along the transition.

The model is built upon an Armington trade framework with endogenous productivity growth driven by both innovation and technology licensing. Innovators invest resources to develop new technologies, while adopters invest resources to use these technologies in intermediate goods production. Adoption is a slow and costly process. If successful, adopters license the technology, use it to produce a new intermediate good with monopolistic competition, and earn profits from selling the good, both domestically and internationally. A share of these profits is paid to innovators as royalty payments. The royalty fee is determined by the bargaining power of the innovator, which in turn is a function of the quality of IP enforcement. Weak IP protection diminishes the innovators' ability to negotiate favorable terms, resulting in under investment in R&D and subsequently reducing long-term growth prospects. High-enforcement countries can impose tariffs on low-enforcement countries to restrict market access for the exports of the latter. To mitigate the inefficiencies, governments engage in bilateral Nash bargaining to negotiate the levels of tariffs and IP protection that maximize their joint surplus. I restrict the governments to just two policy tools—the levels of IP protection and tariffs—similar to what we see in actual deep trade agreements. The payoff function is the pair's Nash bargaining product of dynamic welfare gains, computed as consumption-equivalent units, inclusive of the transition. The trade agreement is cooperative, conditional on both countries having positive welfare gains, and it is assumed to be perfectly enforceable. The model exhibits a balanced growth path (BGP) in which all countries experience uniform growth rates but differ in relative levels. I study both the BGP and the transitional dynamics, since changes in tariffs and the level of IP protection have both growth effects on the BGP and effects along the transition.

International technology licensing, which is measured by royalty payments, is the main channel of technology transfer in the model. Imperfect IPR lowers the amount of royalty payments globally. The model predicts that signing the trade agreement will lead to an increase in royalty payments. This modeling strategy is justified by several salient features of the evolution of royalty payments and their connections to IP reforms within deep trade agreements in recent decades. First, there has been a significant rise in global royalty payments, especially since the 1995s, which has been especially important among innovative countries and between developed and developing economies. Second, countries entering into trade agreements with IP provisions experience an increase in royalty payments following the agreement's implementation. The increase in royalty payments resulting from deep trade agreements is notably more substantial compared to when countries sign trade agreements without IP provisions, and these effects on royalty payments are substantially more pronounced than the effects on bilateral FDI flows or cross-border patenting, both of which have been studied as alternative channels of technology transfer.

The model is calibrated to data on international trade flows, income, innovation, and royalty payments for three countries: the United States, China, and an aggregate rest of the world. Countries are heterogeneous in their innovation and adoption efficiency, their size, the quality of IP protection, and their geography and trade policy. One innovative aspect of my calibration methodology involves using data on royalty payments to estimate the probability of adoption. The model generates a gravity-type equation for royalty payments, which I estimate using state-of-the-art methods developed within the empirical trade literature. The results reveal heterogeneity in the adoption rates across countries and the presence of imperfect IPR in China, reflected in a lower royalty fee paid by Chinese adopters.

I then conduct a counterfactual exercise in which China and the United States negotiate a trade agreement consisting of choosing the levels of US tariffs on Chinese imports, and the level of China's protection on both domestic and foreign IP as part of a Nash bargaining agreement. The introduction of the third country is aimed at aligning the model with data on global trade flows, while focusing on bilateral negotiations. An important component of the trade agreement is that China has to reform its domestic IP laws, which benefits domestic innovators in China. This feature is motivated by current trade agreements that require significant changes in the domestic legislation of participating countries.[4] The agreement is assumed to be an unanticipated, permanent, one-time shock. I solve for the perfect foresight solution of the model after the agreement is signed.

Assuming equal bargaining power in each country, the Nash bargaining agreement implies the removal of US tariffs on imported Chinese products and improvements of IP enforcement in China, for both domestic and foreign IP. This leads to welfare increases in all countries, but the distribution of gains across countries varies along the transition: The US experiences short-term gains, while China experiences short-term losses. The main channels at play are as follows: The trade agreement boosts innovation and growth in the long run worldwide. Innovators, both in China and the United States receive more royalty payments, increasing their returns on R&D. As a result, welfare increases in all countries because higher global innovation drives up the growth rate in the BGP. In China, there are short-term losses because of a higher price of adoption. Adopters face two opposing forces. Access to a larger market, through lower tariffs, encourages adoption; however, the cost of adoption rises as they have to pay more royalties. The net effect is a decline in adoption, leading resources to be reallocated towards innovation in China. In contrast, the United States experiences short-term gains as innovators receive more royalties and the return on innovation rises. The importance of examining transitional dynamics becomes evident through quantitative analysis as it shows significant distributional effects of trade agreements, particularly in the short term.

In the model, trade policy and IP reforms interact in a non-trivial way, both in the long run and along the transition. To gain a deeper understanding of these interactions, I conduct several counterfactual exercises where I analyze the impact of each instrument from the agreement separately. Firstly, changes in tariffs without accompanying improvements in IPR primarily impact short-term dynamics and have a negligible effect on the BGP growth rate. Lower tariffs generate short-term benefits in China but result in short-term losses for the US, with the extent of these losses dependent on the initial IP enforcement in China. Secondly, improvements in IPR without concurrent tariff reductions bring long-term gains but at the cost of larger short-term losses in the country reforming IP enforcement. Thirdly, China gains from independently reforming its IPR, either unilaterally or within the trade agreement. In fact, China consistently has an incentive to enhance its domestic IPR, either unilaterally or

[4] See https://unctad.org/system/files/official-document/iteipc20064_en.pdf.

as part of the trade agreement, with a willingness to improve foreign technology enforcement only if the US offers reduced tariffs. Therefore, tariffs represent a policy instrument for encouraging China to enhance its foreign IPR.

The Nash bargaining agreement is formulated on the basis of various assumptions, and I conduct several counterfactual exercises in which I relax some of these assumptions. First, the Nash bargaining agreement is cooperative. I compare this solution with the Nash equilibrium, where each country optimally selects the value of the instrument while considering the strategies of the other country as given. In this uncooperative agreement, China chooses to improve its enforcement of IPR for domestic technologies while keeping the quality of IP protection for foreign technologies unchanged. Conversely, the United States opts for higher tariffs to decrease foreign competition, especially when the initial IP protection in China is weak. The result is smaller gains for the US and losses for China; both countries experience short-term losses in the short-run. Hence, there are gains for both countries in signing mutually beneficial agreements. Second, the main trade agreement has been designed by a welfare-maximizing government. However, the short-term losses in China that result from the agreement might not be attractive to a government with short-term goals.[5] I show that a shortsighted government—modeled as being more impatient than the consumer and, thus, with a lower discount factor—can prevent short-term losses at the cost of lower overall gains. The reason is that the trade agreement in this case entails smaller improvement in IP enforcement of foreign technology, leading to a smaller increase of the BGP growth rate. Third, the trade agreement is structured with the assumption of perfect enforcement and commitment. However, it is possible that a scenario arises in which China deviates to evade short-term losses. This raises the question: Does the US have a credible threat to deter such behavior and impose consequences on China? I perform a counterfactual in which China deviates a few periods after the agreement enters into force. I then allow the US to impose high tariffs on China as retaliation. In this scenario, China experiences overall losses, while the US realizes greater gains compared to the situation in which it only reverts to the initial tariff levels before the agreement. The presence of a credible threat to raise tariffs in the event of Chinese deviation may deter China from having the incentive to deviate. Finally, the agreement is unanticipated and is implemented immediately after signing it. In reality, trade agreements are hardly ever unexpected, primarily because of the time required for

[5] See Grossman and Helpman (1995) and Grossman (2016).

negotiation, ratification, and implementation (Maggi and Rodriguez-Clare, 2007). Moreover these agreements tend to be gradual. I investigate the potential differences in the agreement's dynamics when it is gradual and anticipated by consumers, innovators, and adopters. I find that this type of agreement mitigates short-term losses in China, leading to overall larger gains and a more gradual adjustment of key economic variables.

Finally, the specific characteristics of the trade agreement hinge on several features of the countries involved in the Nash bargaining negotiation. I investigate which parameters and data moments influence my quantitative results. Specifically, I explore the role of four of them: (i) China's efficiency of innovation; (ii) the initial level of US tariffs on goods imported from China; (iii) China's initial level of IP protection; and (iv) the bargaining power of the parties involved in the agreement. The results indicate that low innovation efficiency could pose challenges for a trade agreement where China promises to improve its IP protection. Moreover, lower initial US tariffs might not incentivize China to strengthen its IP protection, and when China's IP protection is initially weak, the US may be less inclined to reduce tariffs, leading to smaller tariff reductions. Finally, China's bargaining power significantly influences the extent of improvements in foreign IPR and the reduction of US tariffs.

Literature Review The paper is related to several strands of literature. First, it is related to political economy models of trade agreements. Recent papers have studied the welfare effects of trade negotiations on tariffs (see Maggi and Rodriguez-Clare, 2007; Ossa, 2014; Bagwell and Staiger, 2016; Bagwell, Staiger, and Yurukoglu, 2020). However, the literature on trade negotiations involving non-tariff issues, such as IP, remains relatively scarce. On the theory front, Maggi and Ossa (2021) document the change in the nature of trade agreements, studying deep integration from the perspective of the political economy of trade policy; Grossman, McCalman, and Staiger (2021) study governments' incentives to engage in deep integration; and Limão (2007) studies preferential trade agreements that include non-tariff provisions. This paper contributes to existing work by exploring, both theoretically and quantitatively, the dynamic trade-offs of reforming IPR as part of a trade agreement that includes non-tariff issues.

Second, the paper is related to recent quantitative dynamic models of trade, innovation and knowledge spillovers analyzing dynamic gains of trade (Somale, 2021; Buera and Oberfield, 2019; Cai, Li, and Santacreu, 2021; Sampson, 2023; Lind and Ramondo, 2023). The contribution with respect to those studies is to introduce imperfect IPR and study the design of deep trade agreements that include changes in both tariffs and in the quality of IP protection. Moreover, while most of this work studying dynamic gains through innovation has focused on the BGP, very few papers compute welfare gains along the transition. An exception includes Akcigit, Ates, and Impullitti (2018); Perla, Tonetti, and Waugh (2021); Buera and Oberfield (2019). My paper contributes to this literature by providing an evaluation of deep trade agreements that include transitional dynamics.

Third, the paper is related to a large literature studying the effects of IPR improvements on growth and welfare in developing countries (Helpman, 1993; Lai, 1998; Lai and Qiu, 2003; Kwan and Lai, 2003; Yang and Maskus, 2001; Branstetter et al., 2007, 2011; Tanaka and Iwaisako, 2014; Diwan and Rodrik, 1991). Helpman (1993) analyzes, theoretically, the effect of the policy of tightening IPR on the rate of innovation in North and on the welfare in both North and South. In their work, Grossman and Lai (2004) explore a North-South model wherein North exhibits higher innovation efficiency, and they consider globally efficient patent protection regimes. Glass and Saggi (2002); Lai (1998); Tanaka and Iwaisako (2014) extend previous work to introduce FDI. Lai and Qiu (2003) allow for both North and South to be innovators and compare Nash equilibrium of IP protection between North and South. Kwan and Lai (2003) study the transitional dynamics of a shock in IPR protection and account fully for the loss in current consumption and gain in consumption growth due to a tightening IPR protection. Diwan and Rodrik (1991) introduce trade to study the effects of IPR protection. Hoekman and Saggi (2007) study, using a repeated game approach, IP provisions in North-South trade agreements. Finally, Yang and Maskus (2001); Branstetter et al. (2007, 2011) introduce licensing in the model and study the impact of stronger IPR on licensing and innovation. More recently, Hémous, Lepot, and Schärer (2023) study, quantitatively, optimal patent policy in an Eaton and Kortum trade model. My paper contributes to this work by studying, quantitatively, the impact of IP reforms within a trade agreement on welfare, innovation, and licensing.

Fourth, the paper is related to a literature studying the interactions between technology licensing and IP reforms. Branstetter, Fisman, and Foley (2006) investigate the impact of a series of IPR reforms on technology transfer within US multinational firms using royalty payment data. Saggi (1999) examines the choice between licensing and FDI by foreign firms and assesses the varying effects of these technology transfer methods on innovation incentives. Santacreu (2023) investigates the factors influencing royalty payments, with a primary focus on revealing profit-shifting practices related to technology licensing, while considering the impact of IPR as a secondary aspect. My paper contributes to that literature by studying the interaction between international technology licensing and IP reforms within the framework of deep trade agreements.

Finally, my paper is closely related to recent work analyzing the interaction between trade and IPR. Mandelman and Waddle (2019) investigate the interaction between tariffs and IPR enforcement within a quantitative general equilibrium framework. Their research delivers insightful findings: (i) Tariffs can effectively deter weak IP protection, and (ii) weakening IPR enforcement can serve as a deterrent to raising tariffs. In their approach, tariffs are contingent on IPR enforcement, and they evaluate the impact of exogenous shocks on key economic variables. In contrast, this paper treats tariffs and IPR as distinct instruments, chosen optimally to maximize global welfare. My paper is also related to Holmes, McGrattan, and Prescott (2015), who study the welfare effects of improving IPR in China through the lenses of forced technology transfer. Forced technology transfer—i.e., quid-pro-quo practices— allows Chinese firms to receive foreign technology without paying royalties. The main channel is through FDI, as foreign firms that want to operate in the Chinese market form joint ventures with local firms. However, quid-pro-quo practices resemble a situation in which firms first license a technology and then imitate it. The advantage of focusing on licensing is that we can directly measure it across many countries and over time. Consequently, the framework can be expanded to analyze trade agreements involving other countries. Different from their work, this paper develops a quantitative framework to study the interaction between trade and IPR in the context of deep trade agreements.

The remainder of the paper is organized as follows. Section 2 motivates the use of royalty payments as the main measure of technology transfer in the model. Section 3 presents the model and Section 4 discusses the mechanism. Section 5 describes the calibration and counterfactual analysis. Section 6 concludes.

2 Royalty Payments, Technology Transfer, and Deep Trade Agreements

International technology licensing, measured with royalty payments, is the key indicator of technology transfer and IP enforcement in this paper. The underlying assumption is that these payments proportionally represent technology transfer between countries. Moreover, the model predicts that trade agreements with IP provisions have a substantial impact on royalty payments. This raises two key questions regarding (i) the accuracy of royalty payments in reflecting technology transfer, and (ii) the extent to which comprehensive trade agreements affect international technology licensing.

Firstly, the data indicate a substantial increase in global royalty payments over time. In the 1980s, these payments represented a mere 0.06% of the world's GDP, growing consistently to approximately 0.50% by 2019. This upward trend, starting at 0.12% in 1995 and increasing to 0.40% in 2012, signals a noteworthy expansion in technology transfer activities.[6] It is worth noting concerns about potential profit-shifting from high-tax to low-tax countries that could be reflected in royalty payments data (see Santacreu, 2023). Profit shifting would involve rich and innovative countries selling the ownership of their IP to tax havens that typically do not invest resources in R&D. Consequently, the data would indicate that innovative countries receive fewer royalty payments while tax havens receive substantial amounts of royalty payments. The rapid increase in royalty payments observed between developed and developing countries suggests that this growth is not solely driven by tax-avoidance strategies. That paper emphasizes a significant rise in royalty payments between innovative countries, both non-tax havens, and between developed and developing nations that are not classified as tax havens.

Secondly, I explore the relationship between IPR and international technology licensing within the framework of deep trade agreements. Existing studies highlight the positive impact of improved IPR on technology licensing across countries (Branstetter, Fisman, and Foley, 2006). However, the specific dynamics of international technology licensing concerning deep trade agreements with IP provisions remain unexplored due to a lack of data. To address this gap, I use a dataset of RTAs with IP provisions, sourced from Martínez-Zarzoso and

[6] Data from World Development Indicators (WDI) World Bank.

Chelala (2021).[7],[8] These agreements were in force between 1995 and 2012. Additionally, I employ data on bilateral royalty payments from the OECD Balanced Trade in Services dataset, covering 40 countries (excluding tax havens) during the period from 1995 to 2012. I specifically focus on country pairs involving a developed country transferring technology to a developing country and assess the evolution of royalty payments before and after the agreements, distinguishing between RTAs with and without technology provisions. The focus on technology flows between developed and developing countries is driven by empirical findings presented in Appendix A. These results highlight that the impact of RTAs with IP provisions is particularly pronounced in this context, especially when these provisions emphasize patents and IP protection.

Figure 1 shows the evolution of royalty payments from developing countries to developed countries during 1995-2012, before and after they signed an RTA agreement.[9] I split the sample of country-pairs into those that sign only RTAs with IP provisions (solid line) and those that sign only RTAs without IP provisions (dashed line).[10] Royalty payments are normalized to 1 on the year in which the agreement is enforced. Each line in the figure represents the average across all country-pairs of normalized royalty payments.

The figure shows a sharp increase in royalty payments from developing to developed countries following the year in which an RTA with IP provisions enters into force. In contrast, RTAs without IP provisions imply a slower rate of technology transfer to developing economies that sign such an agreement. In Appendix A, I present a comprehensive empirical analysis to show the impact of trade agreements with IP provisions on international technology licensing. This analysis differentiates between country groups based on their level of development.

Finally, technology transfers can occur through various channels that are not reflected in royalty payments, such as FDI or cross-border patenting (see Maskus, 2004, for a review of different types of technology transfer and the importance of licensing). Here, I conduct

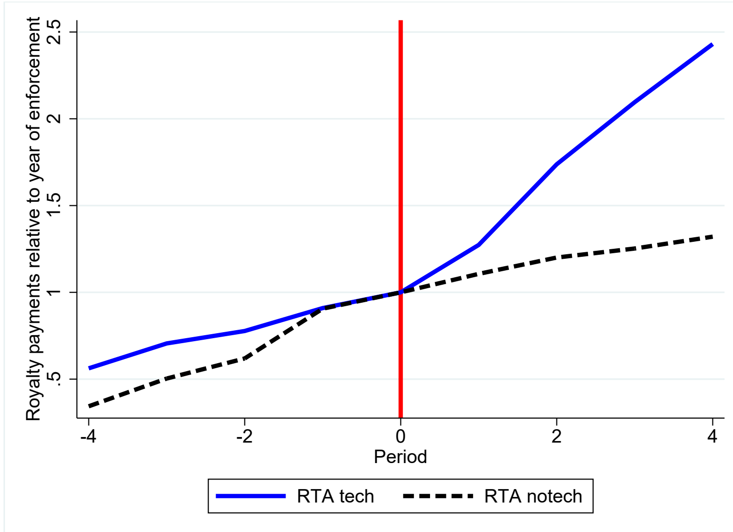
[7] An alternative would be to use measures developed by the World Bank of Deep Trade Agreements: `https://datatopics.worldbank.org/dta/about-the-project.html`.

[8] In Martínez-Zarzoso and Chelala (2021), RTAs are decomposed into those with and without technology provisions. These are RTAs that go beyond the TRIPS agreement that was part of the WTO formation in 1995. They further classify provisions into four subgroups: (1) general intention to transfer technology, (2) technical cooperation, (3) joint R&D effort, and (4) IP.

[9] Developing countries are defined as those with a GDPpc $\leq$ 12,500USD in 2012.

[10] There is a total of 101 pairs that have only RTAs that have IP provisions, 130 pairs with only RTAs with no IP provisions, and 7 pairs that have both types of agreements.

Figure 1: Dynamics of International Technology Licensing During RTAs with IP Provisions

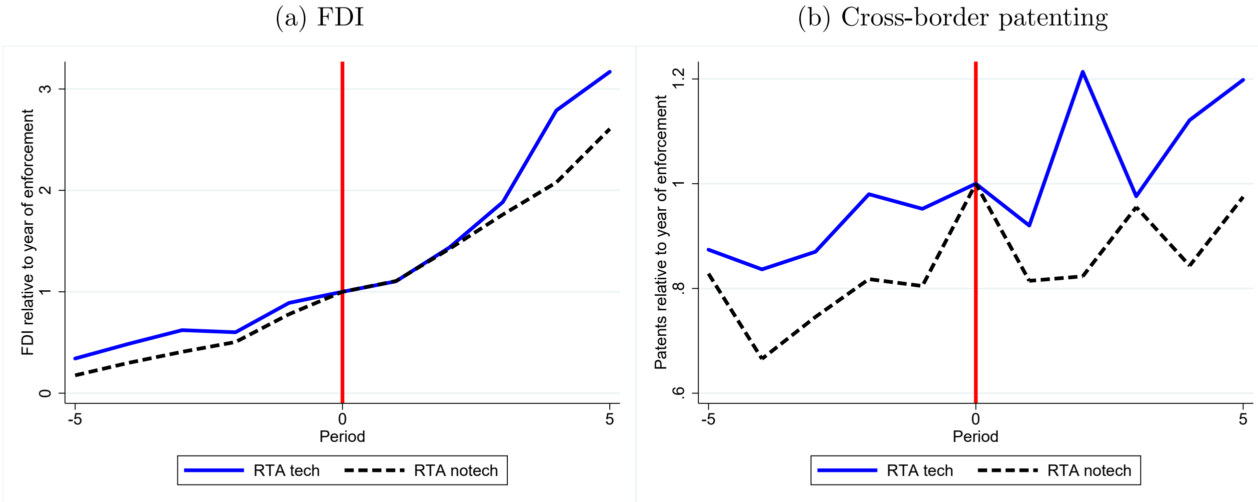


Notes: The figure shows the evolution of royalty payments from developing to developed countries 5 years before and 5 years after they sign a trade agreement with only technology provisions (blue solid line) and with only non-technology provisions (black dashed line). It considers all trade agreements signed between 1995 and 2012. The vertical line at zero represents the time at which the agreement enters into force.

the same analysis from Figure 1, but using data on cross-border patenting and bilateral FDI flows. The data on cross-border patenting are from PATSTAT, whereas the data on FDI are from Larch and Yotov (2022) and Anderson, Larch, and Yotov (2019). Figure 2 illustrates that the contrasting effects of RTAs with IP provisions versus those without IP provisions are significantly more pronounced in the context of royalty payments, compared to alternative technology transfer channels like cross-border patenting or FDI.

While royalty payments alone do not encompass the entirety of technology transfer activities, it has several advantages: (i) Different from other channels, they are easily accessible and quantifiable data; (ii) unlike alternative channels, such as international trade or foreign direct investment (FDI), royalty payments offer a more direct measure of technology diffusion. This is because international licensing transactions leave behind a clear paper trail—contracts through which a patent owner (the technology inventor or exporter) licenses the patent's use to a foreign firm (the technology importer) for the production of goods, with the technology importer compensating the innovator through royalty fees; and (iii) royalty payments increase faster following the enforcement of trade agreements with IP provisions than other channels of technology transfer.

Figure 2: Dynamics of FDI and Cross-Border Patenting During RTAs with IP Provisions



Notes: The figure shows the evolution of FDI flows and cross-border patenting from developing to developed countries 5 years before and 5 years after they sign a trade agreement with technology provisions. It considers all trade agreements signed between 1995 and 2012. The vertical line at zero represents the time at which the agreement enters into force.

In summary, the empirical evidence indicates that when countries engage in trade agreements with IP provisions, there is a significant surge in royalty payments. This surge is notably more substantial compared to cases where countries sign trade agreements lacking such IP provisions. This effect is not only statistically significant but also substantially more pronounced when observed in the context of royalty payments, in contrast to its comparatively milder impact on bilateral FDI flows and cross-border patenting activities. These results underscore the important role that IP regulations play in shaping international technology transfer through licensing.

3 Model

The global economy encompasses M countries indexed by i and n, with time being discrete and indexed by t. The model consists of two main components: a trade block that determines the static equilibrium, taking as given productivity and trade frictions, which include tariffs and iceberg trade costs; additionally, there is a growth block that governs productivity dynamics through innovation and international technology licensing. Imperfect IP protection is reflected in the form of low royalty fees paid to innovators. The presence of tariffs and weak IP enforcement introduces inefficiencies into the model, which can be addressed by governments engaging in bilateral Nash bargaining negotiations.

3.1 Preferences

In each country n, a representative consumer chooses C_{nt} to maximize life-time utility

$$\sum_{t=0}^{\infty} \beta^t \log\left(C_{nt}\right), \tag{1}$$

subject to the budget constraint

$$P_{nt}C_{nt} + P_{nt}B_{nt} + \frac{\eta}{2}\left(B_{nt} - \bar{B}_n\right)^2 = W_{nt}L_{nt} + \Pi_{nt}^{\text{all}} + R_t P_{nt} B_{n,t-1} + \text{IBT}_{nt} + Tr_{nt}, \tag{2}$$

where β is the discount factor, W_{nt} is the wage, L_{nt} is population, Π_{nt}^{all} are the profits of all the firms in the economy, and B_{nt} is a one-period risk-free bond that is traded internationally at the world interest rate R_t. To ensure stationarity and the existence of a unique steady-state solution for bond holdings, I assume there are quadratic costs to adjusting the international portfolio, with $\bar{B}_n$ the steady-state value of bond holdings. These costs are rebated lump sum to consumers as Tr_{nt} (see Ghironi and Melitz, 2007; Heathcote and Perri, 2002). Finally, the consumers get a lump-sum transfer from the government based on the amount of tariff revenues, IBT_{nt}, to be defined later. Consumers lend to innovators and adopters to finance their activities and, in return, get the profits from all firms in the economy.

3.2 Final Production

In each country n, a perfectly competitive final producer demands intermediate inputs to produce a non-traded good according to the constant elasticity of substitution production function:

$$Y_{nt} = \left(\sum_{i=1}^{M} \int_{j=0}^{T_{it}} x_{ni,t}(j)^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

where $x_{ni,t}(j)$ is the amount of intermediate input j demanded by the final producer in country n from country i at time t; T_{it} is the number of intermediate goods produced in country i, to be determined later; and $\sigma > 1$ is the elasticity of substitution across intermediate products.

The demand for intermediate goods is given by

$$x_{ni,t}(j) = \left(\frac{p_{ni,t}(j)}{P_{nt}}\right)^{-\sigma} Y_{nt}. \tag{4}$$

where $p_{ni,t}(j)$ is the price that the final producer in country n pays for an intermediate good j from country i at time t, and P_{nt} is the price index, to be determined later.

Intermediate Producers In each country n, a continuum of monopolistic competitive intermediate producers indexed by j hire labor to produce a traded good according to the constant-returns-to-scale production function:

$$y_{nt}(j) = \Omega_n l_{nt}(j), \tag{5}$$

where $y_{nt}(j)$ is the amount of intermediate good j produced at time t, Ω_n is the fundamental productivity in country n, and $l_{nt}(j)$ is the amount of labor hired by producer j in country n at time t.

Intermediate producers take the demand of final producers as given and choose the price and the amount of labor to hire to maximize profits:

$$\pi_{nt}(j) = \sum_{i=1}^{M} p_{in,t}(j) x_{in,t}(j) - W_{nt} l_{nt}(j), \tag{6}$$

subject to equation (4).

International Trade Intermediate products are traded internationally. Trade is Armington, as varieties are differentiated both between varieties and across countries. Trade is costly and subject to two types of trade barriers. One barrier is an ad-valorem tariff, $\tau_{in,t}$, whereby $1 + \tau_{in,t}$ is the gross tax rate that country i levies on the value of imports from country n at time t. The second barrier is an iceberg transport cost by which, in order to sell one unit of the intermediate good from country n to country i, country n must ship d_{in} units of the good. This means that, in equilibrium, $y_{nt}(j) = \sum_{i=1}^{M} x_{in,t}(j) d_{in}$.

The import share, $\pi_{ni,t}$, is given by

$$\pi_{ni,t} = \frac{X_{ni,t}}{\sum_{m=1}^{M} X_{nm,t}} = \frac{\Omega_i^{\sigma-1} T_{it} \left(W_{it} d_{ni} (1+\tau_{ni,t})\right)^{1-\sigma}}{\sum_{m=1}^{M} \Omega_m^{\sigma-1} T_{mt} \left(W_{mt} d_{nm} (1+\tau_{nm,t})\right)^{1-\sigma}}, \tag{7}$$

where $X_{ni,t}$ represents spending of country n from intermediate goods produced by country i at time t.

Manipulating equation (7), I can obtain an expression of real wages that follows the formula derived in Arkolakis, Costinot, and Rodríguez-Clare (2012).

$$\frac{W_{nt}}{P_{nt}} = \frac{\sigma - 1}{\sigma} \left(\frac{\Omega_n^{\sigma-1} T_{nt}}{\pi_{nn,t}} \right)^{1/(\sigma-1)}.$$

Changes in tariffs drive changes in real wages through the home trade share and through changes in the number of intermediate goods produced in country n at time t, T_{nt}. These goods can be produced either with domestically developed technology (*innovation*) or with foreign technology that has been adopted by the firm (*technology licensing*). I explain these processes in detail next.

3.3 Innovation and Adoption

The number of technologies available to produce intermediate goods, T_{nt}, evolves endogenously through two endogenous processes: innovation and adoption. These processes are solved in two steps. First, innovators and adopters choose the optimal investment in each activity, taking as given the royalty fee. Second, the optimal fee is negotiated as Nash bargaining between the innovator and the adopter.

Innovation In each country n, a monopolist invests final output, H_{nt}^r, to produce a new prototype or technology. The stock of technology innovated in each period is given by the following law of motion:

$$Z_{n,t+1} = \lambda_n T_{nt} \left(\frac{H_{nt}^r}{\bar{Y}_t} \right)^{\beta_r} + Z_{n,t}, \tag{8}$$

where $\lambda_n T_{nt}$ represents the efficiency of innovation, with λ_n, a country-specific parameter that captures innovation policy in the country, and T_{nt}, the stock of knowledge available in country n at time t, capturing a spillover effect by which innovators in n learn from domestic and foreign technology used to produce intermediate goods in that country. Moreover, $\bar{Y}_t$ is world output, which guarantees the existence of a BGP, and $\beta_r \in (0,1)$ represents diminishing returns to adding one extra unit of final output into the innovation process. Equation (8) implies that there is no depreciation of new ideas over time.

Innovators have a monopoly over their technology. The innovator chooses H^r_{nt} to maximize

$$\Delta Z_{nt} V_{nt} - P_{nt} H^r_{nt}. \tag{9}$$

where V_{nt} is the value of an innovation and it will be defined later.

Technology Adoption New technologies developed through innovation need to be adopted for use in the production of a new intermediate product. This process is called adoption and, if successful, an adopter produces an intermediate good with that technology, earns profits, and pays royalties to the innovator.

Adoption is costly and takes time. An adopter j that wants to make a prototype from country n usable for production in country i invests $h^a_{in,t}$ units of final output in adoption. With probability $\varepsilon_{in,t}(j)$ the adopter in country i is successful and can use the technology from country n by paying a licensing fee. The probability of adoption is given by

$$\varepsilon_{in,t}(j) = \bar{\varepsilon}_{in} \left(\frac{h^a_{in,t}(j)}{\bar{Y}_t} \right)^{\beta_a}, \tag{10}$$

where $\bar{\varepsilon}_{in}$ represents the ability of country i to adopt a technology from country n, and $\beta_a \in (0,1)$ is a parameter of diminishing returns to adoption investment.

The evolution in the number of technologies adopted by country i from country n each period is given by the following law of motion:

$$A_{in,t+1} = \varepsilon_{in,t} \left(Z_{nt} - A_{in,t} \right) + A_{in,t}. \tag{11}$$

Here, $Z_{nt} - A_{in,t}$ is the stock of technologies from country n that have not yet been adopted by country i.

Successful adopters start producing the intermediate product and pay a royalty fee to the innovator. I assume that royalties are paid every period as a share of the profits, $\chi_{in,t}\Pi_{it}$, made by the adopter once the technology has been adopted. Here, Π_{it} represents profits by all intermediate producers in country i and are given by

$$\Pi_{it} = (\bar{m} - 1) W_{it} L_i.$$

where $\bar{m}$ is the mark up as is defined as $\bar{m} \equiv \frac{\sigma}{\sigma-1}$.

Endogenous Productivity The number of technologies available to produce intermediate goods, T_{nt}, is given by the number of ideas that have been adopted from around the world:

$$T_{nt} = \sum_{i=1}^{M} A_{ni,t}. \tag{12}$$

T_{nt} also denotes the number of intermediate producers in each country n. Among them, $A_{nn,t}$ license domestically-invented technology, while $A_{ni,t}$ license technologies developed in country i and successfully adopted by country n. Note that T_{nt} also introduces an externality in the innovation function in equation (8), as innovators benefit from ideas they have licensed from around the world.

Optimal Investment into Innovation and Adoption Innovators receive royalties every period from successful adopters around the world. The value for an innovator in country n of a successfully adopted technology by country i is the present discounted value of the royalty payments made by intermediate producers in country i that use the technology from country n; that is,

$$V_{in,t}^{\text{innov}}(j) = \chi_{in,t} \pi_{nt}^{i}(j) + \frac{1}{R_t} \frac{P_{it}}{P_{i,t+1}} V_{in,t+1}^{\text{innov}}(j), \tag{13}$$

where $\pi_{it}^{n}(j)$ are profits made by firm j in country i using technologies that were developed by innovators in country n. These profits include both domestic and export profits.

The value for the innovator in country n of an unadopted technology in country i is given by

$$J_{in,t}^{\text{innov}}(j) = \frac{1}{R_t} \frac{P_{it}}{P_{i,t+1}} \left[\varepsilon_{in,t} V_{in,t+1}^{\text{innov}}(j) + (1 - \varepsilon_{in,t}) J_{in,t+1}^{\text{innov}}(j) \right].$$

With probability $\varepsilon_{in,t}$, the technology is adopted and innovators receive profits forever, which is captured in $V_{in,t+1}^{\text{innov}}(j)$. With probability $(1 - \varepsilon_{in,t})$, adopters are not successful and get the continuation value $J_{in,t+1}^{\text{innov}}(j)$. Because there is a continuum of adopters trying to adopt a technology and ideas do not depreciate over time, there is always an entrepreneur trying to adopt a previously unadopted technology.

Combining all the above expressions, the value of an innovation is the present discounted value of the royalties paid by successful adopters in each country i. Summing across all countries that can adopt a technology, the value of an innovation in country n, V_{nt}, is given by

$$V_{nt} = \sum_{i=1}^{M} J_{in,t}^{\text{innov}}.$$

The first-order condition (FOC) for investment in innovation is

$$P_{nt} H_{nt}^{r} = \beta_r \Delta Z_{nt} V_{nt}. \tag{14}$$

Successful adopters in a country receive the share of profits that is not paid out as royalties to the innovators. Thus, the value for an adopter in country i from successfully adopting a technology from country n is

$$V_{in,t}^{\text{adopt}}(j) = (1 - \chi_{in,t})\pi_{it}^{n}(j) + \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}} V_{in,t+1}(j). \tag{15}$$

The value of an unadopted prototype j that an adopter is trying to adopt is

$$J_{in,t}^{\text{adopt}}(j) = -P_{it} h_{in,t}^{a}(j) + \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}} \{\varepsilon_{in,t} V_{in,t+1}^{\text{adopt}}(j) + (1 - \varepsilon_{in,t}) J_{in,t+1}^{\text{adopt}}(j)\}. \tag{16}$$

In each period t, there are $Z_{nt} - A_{in,t}$ technologies that were not adopted at time t. That is also the number of adopters trying to adopt technologies between time t and time $t+1$.

In equilibrium, $h_{in,t}(j) = h_{in,t}\ \forall j$. Hence, the total amount of output invested to adopt a technology in period t is $H_{in,t}^{a} = \sum_{i=1}^{M}(Z_{nt} - A_{in,t-1}) h_{in,t}^{a}$ and $\varepsilon_{in,t}(j) = \varepsilon_{in,t}$ with

$$\varepsilon_{in,t} = \bar{\varepsilon}_{in} \left(\frac{H_{in,t}^{a}}{\bar{Y}_t}\right)^{\beta_a}. \tag{17}$$

The FOC of adoption is

$$P_{it} H_{in,t}^{a} = \beta_a \varepsilon_{in,t} \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}} (V_{in,t+1}^{\text{adopt}} - J_{in,t+1}^{\text{adopt}}). \tag{18}$$

Note that diminishing returns to innovation and adoption through β_r and β_a introduce

Inada conditions that guarantee that all countries engage in both innovation and adoption. Comparative advantage of innovation versus adoption depends on country-specific parameters, such as λ_i and $\bar{\varepsilon}_{in}$.

The Optimal Royalty Fee Once a technology has been successfully adopted, the innovator and adopter engage in Nash bargaining to determine a one-time royalty fee, $\chi_{in,t} = \chi_{in}$ $\forall t$, that maximizes their joint surplus.[11] This negotiation takes place after the adoption has occurred. If the innovator and adopter fail to reach an agreement on the fee, the innovator would receive zero profits, while the adopter would receive zero profits net of the adoption costs. This outcome arises because the adopter has already incurred the adoption cost regardless of the negotiation's outcome. Specifically, the innovator and adopter negotiate χ_{in} to maximize the following expression:

$$(\chi_{in} W_{in,t}(j) - 0)^{\rho_{in}} \left((1-\chi_{in})W_{in,t}(j) - P_{i,t-1} h^a_{in,t-1}(j) - O_{in,t}(j)\right)^{1-\rho_{in}}. \tag{19}$$

Here, $W_{in,t}(j)$ is calculated as $\pi^i_{nt}(j) + \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}} W_{in,t+1}(j)$. The parameter ρ_{in} represents the bargaining power of the innovator in country n, while $1-\rho_{in}$ denotes the bargaining power of the adopter in country i. Furthermore, the adopter's outside option $O_{in,t}(j)$ is given by $0 - P_{i,t-1} h^a_{in,t-1}(j)$. The optimal royalty fee is determined by the bargaining power of the innovator, ρ_{in}.

A few important points should be noted. First, it is assumed that the fee cannot be renegotiated once agreed upon. Second, the bargaining power of the innovator is assumed to be influenced, among other factors, by the adopter country's IPR quality (Yang and Maskus, 2001; Tanaka and Iwaisako, 2014). Specifically, $\rho_{in} = \bar{\rho}_{in}\eta_i$, where η_i represents the quality of IPR in country i, the technology adopter. A value of $\eta_i = 1$ indicates perfect IPR enforcement, while $\eta_i < 1$ indicates imperfect IPR enforcement. The quality of IPR remains constant unless there are policy changes, such as IPR reforms. To capture improvements in the quality of IPR, I introduce the policy parameter $\xi_{in,t} \in (1, 1/\eta_i)$. Note that, while η_i depends solely on the characteristics of the adopter, $\xi_{in,t}$ varies for each country pair, implying that IPR quality reforms in country i can differ depending on the innovator country. Hence, the royalty fee can be expressed as $\chi_{in,t} = \rho_{in}\xi_{in,t}$, reflecting how improvements in

[11] See Benhabib, Perla, and Tonetti (2021) and Hopenhayn and Shi (2020) for examples of models of licensing where the royalty fee is negotiated.

IPR quality translate into increased bargaining power for the innovator. Note that during the negotiation of the royalty fee at time period t, the value of $\xi_{in,t}$ is assumed to be fixed and constant. This implies that alterations in the policy parameter $\xi_{in,t}$ exclusively impact technologies adopted after the implementation of the reform.

3.4 Market-Clearing Conditions

Finally, I close the model by describing the feasibility condition and the market-clearing conditions:

Feasibility Output is used for consumption, innovation, and adoption; that is,

$$Y_{nt} = C_{nt} + H^r_{nt} + \sum_{i=1}^{M} H^a_{ni,t}. \tag{20}$$

Labor market clearing Labor is used for the production of intermediate goods that are sold in the domestic and foreign markets; that is,

$$W_{nt}L_{nt} = \sum_{i=1}^{M} \Omega_n^{\sigma-1} T_{nt} W_{nt} l_{in,t} = \sum_{i=1}^{M} T_{nt} \frac{p_{in,t}}{\bar{m} d_{in}(1+\tau_{in,t})} x_{in,t} d_{in}. \tag{21}$$

From here,

$$\bar{m} W_{nt} L_{nt} = \sum_{i=1}^{M} \Omega_n^{\sigma-1} T_{nt} \frac{p_{in,t} x_{in,t}}{1+\tau_{in,t}} = \sum_{i=1}^{M} \frac{\pi_{in,t}}{1+\tau_{in,t}} P_{nt} Y_{nt}. \tag{22}$$

Government revenues The government collects tariff revenue that is rebated back to consumers lump sum:

$$\text{IBT}_{nt} = \sum_{i \neq n}^{M-1} \frac{\tau_{ni,t}}{1+\tau_{ni,t}} \pi_{ni,t} P_{nt} Y_{nt}. \tag{23}$$

Bonds market clearing The world market-clearing condition for bonds is given by

$$\sum_{n=1}^{M} B_{nt} = 0. \tag{24}$$

Balance of Payments The balance of payments equation can be expressed as follows:

$$\sum_{i\neq n}^{M-1}\frac{\Omega_i^{\sigma-1}T_{it}p_{ni,t}x_{ni,t}}{1+\tau_{ni,t}}=\sum_{i\neq n}^{M-1}\frac{\Omega_n^{\sigma-1}T_{nt}p_{in,t}x_{in,t}}{1+\tau_{in,t}}+\sum_{i\neq n}^{M-1}RP_{in,t}-\sum_{i\neq n}^{M-1}RP_{ni,t}+R_tB_{n,t-1}-B_{nt},\quad (25)$$

Here, $RP_{in,t}=\chi_{in,t}\frac{A_{in,t}}{T_{it}}\Pi_{it}$ represents royalty payments. Royalties are considered a trade service, and thus, they factor into net exports. Furthermore, international borrowing and lending lead to trade imbalances.

This equation determines the flow of payments to the owners of the main factors of production and is derived by combining the budget constraint in equation (2), the feasibility condition in equation (20), and profit expressions. For simplicity, let's momentarily ignore the presence of international borrowing and lending and transfers in the derivation. Combining the budget constraint and the feasibility constraint, we obtain the following expression:

$$P_{nt}C_{nt}=P_{nt}Y_{nt}-P_{nt}H_{nt}^r-\sum_{i=1}^{M}P_{nt}H_{ni,t}^a=W_{nt}L_{nt}+\Pi_{nt}^{\text{all}}.$$

The term Π_{nt}^{all} encompasses profits of innovators (royalty payments received from around the world) and adopters/intermediate producers (profits net of royalty payments made globally). Thus,

$$\Pi_{nt}^{\text{all}}=\sum_{i=1}^{M}A_{in,t}\chi_{in,t}\frac{\Pi_{it}}{T_{it}}+\sum_{i=1}^{M}A_{ni,t}(1-\chi_{ni,t})\frac{\Pi_{nt}}{T_{nt}}-P_{nt}H_{nt}^r-\sum_{i=1}^{M}P_{nt}H_{ni,t}^a.\quad (26)$$

Eliminating domestic payments and rearranging, we obtain:

$$\Pi_{nt}^{\text{all}}=\sum_{i\neq n}^{M-1}A_{in,t}\chi_{in,t}\frac{\Pi_{it}}{T_{it}}-\sum_{i\neq n}^{M-1}A_{ni,t}\chi_{ni,t}\frac{\Pi_{nt}}{T_{nt}}+\Pi_{nt}-P_{nt}H_{nt}^r-\sum_{i=1}^{M}P_{nt}H_{ni,t}^a.$$

Where the first component of the right-hand side represents royalty payments received by country n from each other country i, the second component represents royalty payments made by country n to each other country i, and the third component represents total profits generated by intermediate producers in country n.

Hence,

$$P_{nt}Y_{nt} = W_{nt}L_{nt} + \sum_{i\neq n}^{M-1} A_{in,t}\chi_{in,t}\frac{\Pi_{it}}{T_{it}} - \sum_{i\neq n}^{M-1} A_{ni,t}\chi_{ni,t}\frac{\Pi_{nt}}{T_{nt}} + \Pi_{nt}.$$

The above expression implies that income is composed of three key components: labor income, net royalties received from the rest of the world (after deducting royalties paid to the rest of the world), and the profits of intermediate producers.

3.5 Nash Bargaining: Tariff and IP Protection Negotiation

Imperfect enforcement of IPR create an inefficiency in the model, leading to underinvestment in innovation and lower long-term growth. To address the inefficiency, governments in high-enforcement countries can sign trade agreements with governments in low-enforcement countries. I assume that country i, a low-enforcement country, and country n, a high-enforcement country, engage in bilateral negotiations regarding tariffs, represented by $\tau_{ni,t}$ and the quality of IPR enforcement, denoted as $\xi_{in,t}$. This negotiation follows the concept of Nash-in-Nash bargaining, as described in Bagwell, Staiger, and Yurukoglu (2021). However, unlike that approach, which is applied to multilateral negotiations where several pairs of countries choose their tariffs, in my model, there are only two countries negotiating an agreement over both tariffs and the quality of IP while the rest of the world maintains fixed tariffs and IPR enforcement.

Formally, when country i negotiates with country n, they determine tariffs, $\tau_{ni,t}$, and the quality of IPR, $\xi_{in,t}$, that maximize their joint surplus, represented by the following equation:

$$\max_{\tau_{ni,t},\xi_{in,t}} \Delta\tilde{W}_i(\tau,\xi)^{\theta}\Delta\tilde{W}_n(\tau,\xi)^{1-\theta} \tag{27}$$

subject to $\Delta\tilde{W}_i > 0$ for all i. Here, $\Delta\tilde{W}_i$ represents the welfare change between signing the trade agreement and remaining in the status-quo (i.e., the initial BGP equilibrium) and the parameter $\theta \in (0,1)$ denotes the bargaining power of country i.

Welfare gains, $\Delta\tilde{W}_i$, are computed in consumption-equivalent units (inclusive of the transition); that is, it denotes the constant amount of consumption that needs to be provided to the consumers in each period to make them indifferent between signing the agreement and remaining in the initial BGP, represented by the star symbol:

$$\sum_{t=0}^{\infty} \beta^t u \left(C_{it}^*(\tau_{ni,0}, \xi_{in,0}) \left(\frac{\Delta \tilde{W}_i}{100} + 1 \right) \right) = \sum_{t=0}^{\infty} \beta^t u \left(C_{it}(\tau_{ni,t}, \xi_{in,t}) \right). \tag{28}$$

The agreement operates under several key assumptions. First, it is a cooperative agreement, contingent on positive welfare gains for both negotiating parties, reflecting their welfare-maximizing objectives. Second, I assume that governments select policy instruments at time zero and these choices remain constant thereafter, i.e., $\tau_{ni,t} = \tau_{ni}$ and $\xi_{in,t} = \xi_{in}$, $\forall t$. Consequently, the new IPR protection applies to technologies adopted after time zero, similar to the approach taken by Grossman and Lai (2004). Third, commitment is assumed, and once the agreement is signed, neither country can deviate. I subsequently relax these assumptions in the quantitative analysis. Finally, governments have two instruments: tariffs imposed by the high-enforcement country and IP reforms carried out by the low-enforcement country. Achieving the first-best outcome might need extra instruments like R&D or adoption subsidies, which are not within the scope of this paper. For instance, in the model, technology licensing from both domestic and foreign technology has a positive impact on innovation through higher T_{nt} in equation (8). This has been documented in Shim (2023) in the context of licensing contracts between South Korea and Japan. Indeed, they find that subsidizing adoption and R&D investment is optimal depending on the position along the development path. Similarly, Akcigit et al. (2023) find increased patents and citations by foreign firms to US start-ups following cross-border investment from Chinese venture capitalists.

3.6 Equilibrium

For all i and n, an equilibrium in which all firms behave symmetrically is defined as a vector of policy instruments $\{\tau_{nin,t}, \xi_{in,t}\}_{t=0}^{\infty}$, an initial vector $\{A_{in,0}, Z_{n,0}\}$, a set of parameters $\{\sigma, \beta_r, \beta_a, \theta\}$ that are common across countries, a set of parameters $\{\lambda_n, \bar{\varepsilon}_{in}, d_{in}, \eta_i, \bar{\rho}_{in}\}$ that differ across countries, a sequence of aggregate prices and wages $\{P_{it}, W_{it}, R_t, V_{it}\}_{t=0}^{\infty}$, a sequence of intermediate prices $\{p_{in,t}\}_{t=0}^{\infty}$, a sequence of royalty fees, $\{\chi_{in,t}\}_{t=0}^{\infty}$ a sequence of value functions $\{V_{in,t}^{\text{adopt}}, V_{in,t}^{\text{innov}}, J_{in,t}^{\text{adopt}}, J^{\text{innov}}, W_{in,t}, O_{in,t}\}_{t=0}^{\infty}$, profits $\{\Pi_{it}, R_{in,t}, \text{IBT}_{it}\}_{t=0}^{\infty}$, a sequence of quantities $\{Y_{it}, H_{it}^r, H_{in,t}^a, \pi_{in,t}\}_{t=0}^{\infty}$, and laws of motion $\{A_{in,t+1}, Z_{nt}\}_{t=0}^{\infty}$ such that:

1. $\{Z_{nt}, A_{in,t+1}\}_{t=0}^{\infty}$ satisfy the law of motion in equations (8) and (11).

2. Given prices, allocations solve the consumer's problem maximizing equation (1) subject to (2).

3. Given prices, allocations solve the final producer's problem yielding equation (4).

4. Given prices, allocations solve the intermediate producer's problems in equation (6) subject to (4).

5. Given prices, allocations solve the innovators' and adopters' problems yielding equations (14) and (18).

6. The royalty fee is determined as the result of Nash bargaining between the innovator and adopter in equation (19).

7. Tariff and quality of IPR bargaining equilibrium are defined as a vector of tariffs, τ, and IPR enforcement, ξ, such that for each pair $\{i, n\}$ these vectors solve equation (27), taking as given all other tariffs and IPR enforcement. I assume that the agreement is perfectly enforced. In other words, the equilibrium policies and outcomes remain optimal over time.

8. Feasibility is satisfied in equation (20).

9. Prices are such that all markets clear (labor market, government tax revenues, consumer's budget constraint, and bond market) in equations (22)-(25).

A list with all the equations of the model is presented in Appendix C.

3.7 Balanced Growth Path

Cross-country adoption guarantees that the model has a unique BGP equilibrium in which all countries grow at a constant and uniform rate but differ in relative levels. Growth in the BGP is endogenous. Changes in tariffs, τ, and in the quality of IPR enforcement, ξ, have both growth and level effects. Here I characterize the BGP growth rate of the economy (the remaining variables on the BGP are characterized with Appendix E). I stationarize all the endogenous variables so that they are constant on the BGP, denote the normalized variables with a hat, remove all time subscripts in the derivation, and characterize the variables on the BGP with a star.

The stock of knowledge T_i^* grows at the constant rate $g*$. Combining equations (8) and (11), I can express the BGP growth and relative productivity of country i (relative to a reference country M) as

$$g^* \hat{T}_i^* = \sum_{n=1}^{M} \frac{\varepsilon_{in}^*}{\varepsilon_{in}^* + g^*} \lambda_n \hat{T}_n^* \left(\frac{\hat{H}_n^{r*}}{\hat{\hat{Y}}^*} \right)^{\beta_r}, \tag{29}$$

where $\hat{T}_n^* = \frac{T_n^*}{T_M^*}$.

The Perron-Frobenius theorem guarantees that there is a unique growth rate on the BGP in which all countries grow at the same rate g^* (see Eaton and Kortum, 1999, for a reference). The expression for the growth rate can be expressed in matrix form as

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

Proposition 1 *If the matrix $\Delta(g^*)$ is a positive definite, then there exists a unique positive BGP rate of technology $g^* > 0$, given research intensities and diffusion parameters. Associated with that growth rate is a vector T^* (defined up to a scalar multiple), with every element positive, which reflects each country's relative level of knowledge along that BGP. Changes in tariffs, τ, and IPR, χ, have an effect on g^* and T^* through changes in $\hat{H}^{r*}$ and ε^*, which in turn depends on $\hat{H}^{a*}$.*

In Appendix E, I provide details on the derivation of the BGP, and in Appendix D, I summarize the equations of my model's equilibrium conditions after normalizing all endogenous variables.

4 Understanding the Model: Sources of Inefficiency and Main Channels

Before moving to the quantitative analysis, I study the main channels at play in a simplified version of the model. Consider a two-country world composed of North and South with varying levels of IP enforcement. North enforces IP rights perfectly ($\eta_N = 1$), while South exhibits imperfect IP enforcement ($\eta_S < 1$). Additionally, North imposes tariffs on imports from South, whereas South does not impose any tariffs. North and South engage in a

Nash bargaining negotiation to determine the level of IP enforcement in South (ξ_{Sn} with $n \in \{N, S\}$) and the tariff level imposed by North on imports from South (τ_{NS}). The outcome of the agreement is that South improves IP protection on both domestic and foreign IP, and North removes tariffs on imports from South. Three questions emerge: First, what are the key inefficiencies that the trade agreement seeks to address? Second, what are the mechanisms through which trade agreements impact innovation, growth, and welfare? Third, what specific characteristics of the countries involved in the negotiation may influence the outcome of this trade agreement?

The sources of inefficiencies The model presents several inefficiencies arising from imperfect IP enforcement and existing tariffs before the trade agreement. The trade agreement aims to address these inefficiencies and enhance economic outcomes for both countries.

Imperfect IP enforcement in South enables IP infringement, which diminishes incentives for domestic and foreign investment in R&D. The presence of tariffs imposed by North creates trade barriers, restricting market access for South's products and diminishing the potential gains from trade.

Countries with low IP enforcement do not fully internalize the negative impact of their actions on R&D investment and the global growth rate. Policies that enhance IP protection can help rectify these inefficiencies, albeit at the cost of low-IP-enforcement countries facing higher adoption costs. Tariffs can be employed as a means to incentivize low-enforcement countries to improve their IP protection, thus addressing the inefficiency.[12]

The main channels An increase in ξ_{Sn}, with $n = \{N, S\}$, reduces IP infringements and encourages innovation in both countries. Innovation efforts increase in both North and South as innovators from both countries receive higher royalty payments. This manifests through an increase in the value of an innovation, V_{nt}, in both countries. As a result, R&D spending, H^r_{nt}, increases both in North and in South:

$$H^r_{nt} = \left(\beta_r \bar{Y}_t^{\beta_r} \lambda_n T_{nt} \frac{V_{nt}}{P_{nt}} \right)^{1-\beta_r}. \tag{30}$$

Tariff reductions also stimulate innovation in South by expanding its market size, which

[12] Importantly, changes in tariffs and IP protection also have spillover effects on other countries when the analysis is extended to a multi-country framework.

manifests in higher profits through a larger export share, $\pi_{NS,t}$. This in turn impacts V_{St} positively.

Adoption in North increases since there are more technologies being produced both domestically and internationally, and the royalty fee paid by North remains unchanged. However, adopters in South face two opposing forces. On the one hand, lower tariffs increase profits through a higher export share and, hence, the incentives to adopt. On the other hand, a higher royalty fee implies a lower value of adoption. Through the FOC of adoption:

$$H^{a}_{Sn,t} = \left(\beta_a \bar{\epsilon}_{Sn} \frac{V^{\text{adopt}}_{Sn,t} - J^{\text{adopt}}_{Sn,t}}{P_{St}} \right)^{\frac{1}{1-\beta_a}} \tag{31}$$

When ξ_{Sn} increases, then $V^{\text{adopt}}_{Sn,t} - J^{\text{adopt}}_{Sn,t}$ decreases. The elasticity of adoption with respect to changes in the value of adopted technologies is given by $1 - \beta_a$. Reduced adoption rates have a negative impact on innovation through two channels: (i) a lower probability of adoption, $\varepsilon_{Sn,t}$, results in a lower value of innovation, represented by $J^{\text{innov}}_{Sn,t}$, thus adversely affecting innovation; and (ii) the adoption of fewer foreign technologies also leads to a decrease in T_{St}, which in turn diminishes innovation through the externality effect on innovation efficiency. Therefore, the processes of innovation and adoption are linked, and the nature of this connection depends on the royalty fee, $\chi_{Sn,t}$.

The increased innovation in both North and South contributes to a higher BGP growth rate, denoted as g^* through equation (29). Changes in growth rates are important in generating dynamic gains from trade agreements. Consequently, both countries stand to benefit from a higher long-term growth rate. However, the distribution of welfare gains during the transition period varies significantly between the two countries. South gains from reduced tariffs, but it faces higher royalty fees, which increase the costs of the adoption process. In contrast, North benefits from a lower home trade share but faces a trade-off: It loses the ability to manipulate the terms of trade and forgoes tariff revenues. It is important to note that tariffs primarily affect the static aspects of the trade agreement, whereas changes in the level of IP protection carry dynamic implications. The short-term impacts of this agreement depend on country-specific characteristics, which I explore in the next discussion as well as in the quantitative analysis.

What characterizes the trade agreement? The details of the trade agreement and its effects on welfare, innovation, and growth are contingent on several crucial factors. These include the bargaining power of the negotiating parties, innovation efficiency, the initial tariffs and IP enforcement levels, and the comparative advantage of innovation versus adoption. I offer a brief insight into these aspects below, but I will provide more details in the quantitative section.

The bargaining power of the negotiating parties reflects their preferences on tariffs and IP enforcement. When North has more bargaining power, it might be less inclined to reduce tariffs unless South offers significant improvements in IP protection. Conversely, a stronger bargaining position for South could result in fewer concessions in IP protection in exchange for more substantial reductions in tariffs.

The initial level of tariffs plays a crucial role in motivating the South to reform its IP protection. Lower initial tariffs may provide South with less incentive to enhance its IP protection compared to scenarios with higher initial tariffs. Moreover, as North reduces tariffs in exchange for better IPR, there is a trade-off: Good IPR increases royalty payments to innovators, but lower tariffs worsen the terms of trade in North. The balance depends on the initial level of IP protection in South. If IP protection is very weak, North may prioritize obtaining more royalties over favorable terms of trade. Conversely, if IPR protection is already strong in South, North may prioritize favorable terms of trade.

To fully capitalize on the benefits of the trade agreement, South must make domestic improvements in its IP regime. These trade agreements often involve restructuring the court system in South and granting increased protection to domestic innovators, which is then extended, sometimes at lower levels, to foreign innovators. Therefore, the efficiency of innovation in South is critical for the country to realize gains from the agreement. Additionally, another key factor is the comparative advantage of innovation with respect to adoption in South and the elasticity of adoption, which is given by equations (30) and (31). If the comparative advantage of innovation in South is low, improving domestic IPR may not yield significant benefits, since the country is relatively better at adopting and this activity becomes more costly. Similarly, if the elasticity of adoption is low, the negative effects of a higher price of adoption may not be substantial.

These factors shape the overall outcome of the trade agreement, highlighting the complex interplay between IP enforcement and tariffs. I explore these different scenarios further in the quantitative analysis.

5 Quantitative Analysis

I use the model to study, quantitatively, the dynamic implications of a Nash bargaining trade agreement between China and the United States. This is motivated by one of the longstanding concerns of the United States, namely the alleged misappropriation and forced transfer of American technology by Chinese companies. At the end of the US-China trade war, the two countries agreed to the phase one agreement, which included provisions aimed at addressing these concerns. China committed to improving its protection of IPR and the United States agreed to lower tariffs on certain Chinese imports as China fulfilled its commitments. The reduction in tariffs was seen as an incentive for China to comply with the terms of the agreement.

In the counterfactual analysis, I model a similar agreement in which China chooses the quality of its IP protection, while the United States decides on tariffs for Chinese imports. The agreement is assumed to be perfectly enforced, unanticipated, permanent, and a one-time shock with perfect foresight.[13]

I then explore the dynamic trade-offs within the trade agreement by considering various alternative scenarios. First, I analyze the interaction between trade policy and IP reforms, examining the impact of each instrument separately. Second, I challenge some of the assumptions underlying the Nash bargaining process. Lastly, I explore the model's characteristics that play a crucial role in determining a specific solution within the Nash bargaining negotiation.

5.1 Calibration

The model is calibrated to match data on trade flows, geography, income, R&D spending, and international technology licensing for a sample of countries that are aggregated into three regions: the United States, China, and an aggregate rest of the world.[14] I set the

[13] I abstract away from a potential hold-up problem as in Celik, Karabay, and McLaren (2020) since there is no upfront investment needed ahead of the agreement. Indeed, this is an agreement on flows given it involves more royalty payments and lower tariffs.

[14] The quantitative analysis has the potential for broader application to a greater number of countries or regions. However, the primary focus of this paper is to examine bilateral trade agreements, with a

initial period at 2000, which predates China's entry into the WTO.[15] I provide details on the calibration strategy next and report the calibrated parameters in Table 1.

Common parameters from the literature The Armington elasticity σ is calibrated to 5, which implies a trade elasticity of 4, as is common in the trade literature (see Waugh, 2010). I set the discount factor β to 0.98, which implies an annual interest rate of 3%.

Trade costs and relative productivity I calibrate trade costs, $d_{in}(1+\tau_{in})$, and productivity, $\Omega_n^{\sigma-1}T_n$ with gravity methods. From the expression for country i's imports from country n,

$$X_{in,t} = T_{nt}\Omega_n^{\sigma-1}\left(W_{nt}d_{in}(1+\tau_{in})\right)^{1-\sigma}X_{it},$$

we can write the following reduced-form gravity equation:

$$X_{in,t} = \exp\left(\beta_{RTA}RTA_{in,t} + fe_{nt} + \mu_{it} + \kappa_{in}\right)\epsilon_{in,t}, \tag{32}$$

where $RTA_{in,t}$ is a dummy that takes the value of 1 if country i and country n had a regional trade agreement in period t, and zero otherwise; $fe_{nt} = \Omega_n^{\sigma-1}\left(W_{nt}\right)^{1-\sigma}$ and $\mu_{it} = X_{it}$ are exporter-time and importer-time fixed effects, respectively; and $\kappa_{in} = \left(d_{in}(1+\tau_{in})\right)^{1-\sigma}$ are bilateral fixed effects, including tariffs. The term $\epsilon_{in,t}$ is the error term in the regression.

I estimate equation (32) using panel data for 69 countries and the period 1986-2006. The database reports bilateral trade, including international and intra-national trade, from Centre for Prospective Studies and International Information (CEPII) and United Nations Industrial Development Organization (UN UNIDO) databases.

I then follow the two-stage approach proposed by Agnosteva, Anderson, and Yotov (2019) and Anderson and Yotov (2016) to obtain estimates of bilateral trade costs. Agnosteva, Anderson, and Yotov (2019) demonstrate that the "standard" gravity variables (e.g., distance,

specific emphasis on understanding their effects on the countries that are directly involved in signing these agreements.

[15]The assumption that China was on a BGP in 2000 serves as a simplification strategy for analysis and calibration purposes. Another advantage of this assumption is that it allows me to isolate the transitional dynamics resulting from joining the trade agreement from the natural transitional dynamics that stem from the country converging to its BGP. By separating these two sets of transitional dynamics, we can gain a clearer understanding of the specific impacts of policy changes. However, I acknowledge that this assumption may not perfectly reflect the complexities of China's economic reality in 2000.

contiguity, common official language, etc.) do well in predicting relative bilateral trade costs; however, they fail to capture the level of bilateral trade costs (e.g., they underpredict the bilateral trade costs for the poor countries and overpredict them for the more developed countries). The first stage consists of recovering the estimated pair fixed effects from equation (32). The second stage consists of estimating the pair-fixed effects on gravity variables, such as geography, common border, or common language. This method allows me to recover estimates of the pair-fixed effects that cannot be identified directly in the first stage due to missing or zero trade flows. Then, trade costs are estimated as

$$\left(d_{in}(1+\tau_{in,2000})\right)^{1-\sigma} = \exp\left(\beta \text{RTA}_{in,2000} + \hat{\kappa}_{in}\right),$$

where $\hat{\kappa}_{in}$ is the predicted value from estimating κ_{in} on standard gravity variables. The use of internal trade allows me to set all internal trade costs to one and all international fixed effects relative to the intra-national ones. I then use data on bilateral tariffs for the year 2000 from the United Nations Conference on Trade and Development (UN-CTAD) to calibrate $\tau_{in,2000}$ and back out the iceberg transport costs, d_{in}, from the gravity estimation results setting $\sigma = 5$. I then aggregate the calibrated d_{in} in three groups: the United States, China, and the rest of the world. To calculate trade costs for both China and the United States with the rest of the world, I use a weighted average of trade costs, weighted by bilateral trade flows.

Finally, using the estimated value for the exporter-time fixed effect, fe_{nt}, when $t = 2000$, as well as data on GDP per capita, and $\sigma = 5$, I follow Waugh (2010) to recover $\Omega_n^{\sigma-1} T_n$. I then aggregate the estimated productivity in three groups: the United States, China, and the rest of the world. To create a measure of productivity for the rest of the world, I compute a weighted average of productivity across countries, with the weights determined by each country's GDP. The results for trade costs and productivity are reported in the top panel of Table 1.

The royalty fee structure I calibrate the royalty fee structure in the initial BGP as follows. Recall that the royalty fee is given by $\chi_{in} = \bar{\rho}_{in}\eta_i\xi_{in}$. In the initial BGP, I set $\xi_{in} = 1$. Then, I choose the value of $\bar{\rho}_{in}$ according to the 25% patenting rule. The 25% rule refers to a technique for determining royalties, which stipulates that a party selling a product based on another party's IP must pay that party a royalty of 25% of the gross profit made from the sale.[16] The 25% rule was initially invented by Goldscheider, Jarosz, and Mulhern (2018) and is used in actual licensing and litigation settings. It assumes that the licensor invented the IP but does not take on the risk associated with developing or selling the product. In the context of my model, this implies that, since adopters incur costs to learn how to use the technology, they may need a lower royalty fee to have incentives to invest in adoption.[17] Below, I describe how I estimate the quality of IP enforcement using data on royalty payments.

Probability of Adoption and the quality of IPR A novelty of the calibration strategy in this paper is to estimate the probability of adoption, ε_{in}, and the quality of IP enforcement, η_i, using data on bilateral royalty payments and gravity methods.

In the model, royalty payments from country i to country n are given by

$$RP_{in,t} = \frac{A_{in,t}}{T_{it}} \chi_{in,t} \Pi_{it}.$$

Solving for equations (8) and (11) on the BGP, I obtain an expression for royalty payments given by

$$RP_{in,t} = \bar{\rho}_{in} \eta_i \frac{\varepsilon_{in}}{\varepsilon_{in} + g} \lambda_n T_{nt} \left(\frac{H_{nt}^r}{\bar{Y}_t} \right)^{\beta_r} \Pi_{it}. \tag{33}$$

That equation can be expressed as a gravity-type equation of royalty payments that depend on exporter-time and importer-time fixed effects as well as time-invariant bilateral fixed effects:

$$RP_{in,t} = \exp \left(\sum_{k \in \{\mathrm{T,NT}\}} \mathrm{RTA}_{int}^k + S_{nt} + F_{it} + fe_{in} \right) * u_{int}, \tag{34}$$

with RTA_{int}^k an RTA with technology (T) and non-technology (NT) provisions (Martínez-Zarzoso and Chelala, 2021), $fe_{in} = \log \left(\bar{\rho}_{in} \frac{\varepsilon_{in}}{\varepsilon_{in}+g} \right)$, $S_{nt} = \log \left(\lambda_n T_{nt} \left(\frac{H_{nt}^r}{\bar{Y}_t} \right)^{\beta_r} \right)$, and $F_{it} = \log \left(\eta_i \frac{\Pi_{it}}{T_{it}} \right)$.

I estimate equation (34) using data on royalty payments for 40 countries—excluding tax havens—during the period 1995-2000, and with PPML methods, as recommended by Baier and Bergstrand (2007); Silva and Tenreyro (2006); Yotov et al. (2016); Zylkin (2018). This

[16] `https://assets.kpmg/content/dam/kpmg/pdf/2015/09/gvi-profitability.pdf`.

[17] Alternatively, this parameter could be the result of a negotiation process in which the innovator and adopter split their surplus, as in Benhabib, Perla, and Tonetti (2021) and Hopenhayn and Shi (2020).

estimation approach has several advantages. First, as Baier and Bergstrand (2007) show, including time-invariant bilateral dummies allows me to control for potential endogeneity of RTAs (if they are not arbitrarily assigned), as these dummies control for all unobserved heterogeneity related to each country-pair. Second, PPML methods can account for zeros in the dependent variable and can deal with heteroskedasticity of the error term in the gravity equation. The results from the estimation are reported in Table A.1 in Appendix A.

I recover ε_{in} from the bilateral fixed effects, assuming a productivity growth rate of 1.85% and setting $\bar{\rho}_{in} = 0.25$, following the 25% patenting rule. Finally, I impose adoption within the country so that $\varepsilon_{ii} = 0.5$, which implies that domestic adoption occurs every 2 years, as it was established to be the case for the United States (Cai, Li, and Santacreu, 2021; Caballero and Jaffe, 1993). I take the cross-country average of the parameters of diffusion for the United States, China, and the rest of the world. For the rest of the world, I take a weighted average using bilateral flows of royalty payments as the weights. On average, it takes countries about 3 years to adopt a foreign technology. The results are reported in Table 1.

Finally, I calibrate the IPR enforcement from the importer-time fixed effects in equation (34). In particular, I estimate the following regression

$$F_{it} = \beta_0 \log(GDP_{it}) + \beta_1 \log(GP_{it}) + \mu_{it}, \tag{35}$$

where GDP_{it} represents gross domestic product (GDP) of country i from CEPII and GP_{it} is an index of patent rights, measured with the Ginarte-Park index (Ginarte and Park, 1997).

As a way to approximate the quality of IP enforcement, I calculate the time-averaged estimate of $\hat{\beta}_1 \log(GP_{it})$. I then express this measure relative to the United States. Here, the assumption is that there is perfect enforcement of IPR in the United States, but partial enforcement in China and the rest of the world. That is, $\eta_{\text{US}} = 1$. However, Chinese adopters as well as adopters in the rest of the world pay only a fraction of the agreed-upon royalty fee, either domestically or internationally, so that $\eta_i < 1, \forall\, i = \{\text{China}, \text{ROW}\}$. I again compute the weighted average across all countries in the rest of the world, using as weights the GDP per capita of each country. The findings reveal that $\eta_{\text{China}} = 0.4$, implying a 10% royalty fee paid by China for both domestic and foreign technologies.

Parameters calibrated within the model recursively The remaining parameters, namely β_r, β_a, λ_n, Ω_n, and $\bar{\varepsilon}_{in}$, are calibrated using a recursive algorithm developed by Cai, Li, and Santacreu (2021), which involves solving the model on the BGP. The values of β_r and λ_n are determined by targeting a productivity BGP growth rate of 1.85% and exactly matching R&D intensity data in 2000, based on the expression for the BGP growth rate in equation (29) and the Perron-Frobenius theorem. With these parameters in place, we can derive a value for T_n, which, in turn, allows us to infer Ω_n from the estimated $\Omega_n^{\sigma-1}T_n$ in equation (32). Finally, I equate β_a to β_r since there is no bilateral data available on adoption spending and obtain the value of $\bar{\varepsilon}_{in}$ by setting ε_{in} to its estimated value in equation (33).

Table 1: Calibrated parameters

Parameter	Value	Source
$\Omega_{\text{US}}\left(T_{\text{US}}\right)^{1/\sigma-1}$	18.6	Gravity trade
$\Omega_{\text{ROW}}\left(T_{\text{ROW}}\right)^{1/\sigma-1}$	5.98	Gravity trade
$\Omega_{\text{China}}\left(T_{\text{China}}\right)^{1/\sigma-1}$	1.00	Gravity trade
$d_{\text{USA,ROW}}(1+\tau_{\text{USA,ROW}})$	1.95	Gravity trade
$d_{\text{USA,China}}(1+\tau_{\text{USA,China}})$	1.80	Gravity trade
$d_{\text{ROW,USA}}(1+\tau_{\text{ROW,USA}})$	2.48	Gravity trade
$d_{\text{ROW,China}}(1+\tau_{\text{ROW,China}})$	2.15	Gravity trade
$d_{\text{China,USA}}(1+\tau_{\text{China,USA}})$	3.23	Gravity trade
$d_{\text{China,ROW}}(1+\tau_{\text{China,ROW}})$	2.53	Gravity trade
L_{US}/L_{China}	0.23	CEPII
L_{ROW}/L_{China}	1.82	CEPII
$\varepsilon_{\text{USA,ROW}}$	0.28	Gravity royalties
$\varepsilon_{\text{USA,China}}$	0.33	Gravity royalties
$\varepsilon_{\text{ROW,USA}}$	0.34	Gravity royalties
$\varepsilon_{\text{ROW,China}}$	0.15	Gravity royalties
$\varepsilon_{\text{China,USA}}$	0.28	Gravity royalties
$\varepsilon_{\text{China,ROW}}$	0.33	Gravity royalties
β_r	0.52	Match $g = 1.85\%$
β_a	0.52	Set $\beta_a = \beta_r$
λ_{US}	0.40	Match R&D intensity in USA
λ_{ROW}	0.50	Match R&D intensity in ROW
λ_{China}	0.18	Match R&D intensity in China
$\bar{\rho}_{in}$	0.25	Royalty fee
η_{US}	1.00	IP enforcement in USA
η_{China}	0.40	IP enforcement in China
η_{ROW}	1.00	IP enforcement in ROW

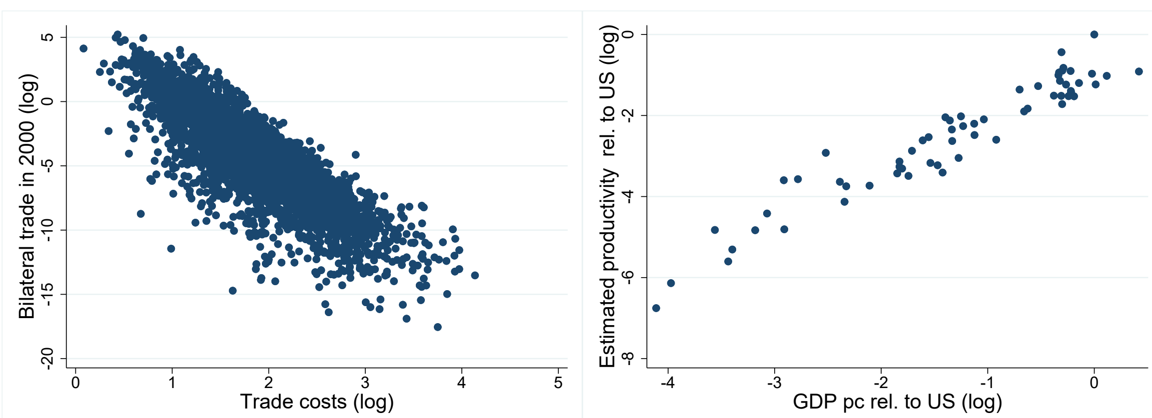
5.2 Model Validation

Prior to conducting counterfactual analysis, I provide model validation by examining the estimates derived from the two key gravity equations in the model. The first equation pertains to trade flows, yielding estimates for trade costs and productivity (equation 32). The second equation relates to royalty flows and provides estimates for the quality of IP enforcement (equation 33).

Trade costs and productivity Figure 3 shows, in the left panel, the relation between trade flows in the data and trade costs obtained from estimating the gravity equation (32) with PPML methods and pair fixed effects. The right panel shows the relation between relative productivity estimated from the exporter-time fixed effect and GDP per capita in the data (relative to the US). The estimated trade costs exhibit a negative relationship with observed trade flows. Additionally, there is a strong positive correlation between the estimated productivity and the actual GDP per capita levels in the data. Hence, the model can produce estimates of trade costs and productivity that are consistent with the data on trade flows and GDP per capita.

Figure 3: Estimated trade costs and productivity using gravity methods

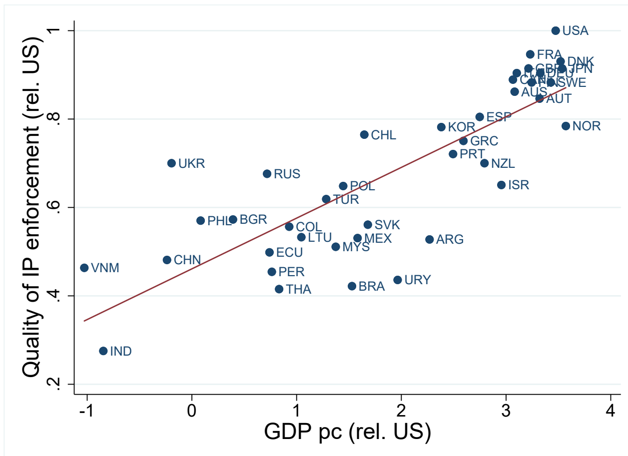
(a) Trade costs $d_{in}(1 + \tau_{in,t})$ (b) Productivity (relative to US)



Notes: The figure shows, in the left panel, the relation between trade flows in the data and trade costs obtained from estimating the gravity equation (32) with PPML methods and pair-fixed effects. The right panel shows the relation between relative productivity estimated from the exporter-time fixed effect and GDP per capita in the data (relative to the US).

Quality of IP enforcement Figure 4 presents a comparison between the quality of IP enforcement, as calculated from equation (35), and GDP per capita data. The figure shows a general trend where countries with higher GDP per capita tend to have better quality in protecting IPR. This finding is consistent with richer countries having more effective IP protection.

Figure 4: Quality of IP enforcement and GDP pc, relative to the United States



Notes: The figure shows the relation between the quality of IP enforcement (relative to the US) and the GDP pc (relative to the US), averaged over the period prior to 2000.

5.3 The Design of the Trade Agreement: Nash Bargaining Equilibrium

The trade agreement consists of choosing two policy parameters: US tariffs on imports from China to the United States, $\tau_{\text{USA,China}}$, and the quality of China's IP protection, $\xi_{\text{China},n}$ with $n \in \{\text{China}, \text{USA}\}$. The improvement in IPR applies to adopters of both domestic and foreign IP, albeit with varying degrees of intensity. In other words, $\xi_{\text{China,US}}$ may not necessarily equal $\xi_{\text{China,China}}$. The details of the trade agreement are determined as the solution of the following Nash bargaining problem:

$$\max_{\tau,\xi} \Delta\tilde{W}_{\text{USA}}(\tau,\xi)^{\theta} \Delta\tilde{W}_{\text{China}}(\tau,\xi)^{1-\theta}, \tag{36}$$

subject to $\Delta\tilde{W}_i > 0 \ \forall i \in \{\text{USA}, \text{China}\}$. Here, $\Delta\tilde{W}_i$ is the welfare change, in consumption-equivalent units, between staying in the initial BGP or signing the agreement and staying there forever, as in equation (28), and $\theta \in (0, 1)$ is the bargaining power of the United States. Welfare gains are computed inclusive of the transition.[18]

The agreement is assumed to have perfect enforcement, remains unanticipated by economic agents (including innovators, adopters, producers, and consumers), and is permanent. In other words, the countries choose the values of these policy instruments today and commit to maintaining these values indefinitely.

The model is solved with perfect foresight.[19]

The economy is initially at the BGP. In period 1, China and the United States sign the trade agreement as the solution of the problem in equation (36). The Nash bargaining outcome, reached with both parties having equal bargaining power ($\theta = 0.5$), results in the elimination of US tariffs on Chinese imports and an improvement in the quality of Chinese IP enforcement. This improvement leads to an increase in the domestic royalty fee from 10% to 25%, while the royalty fee paid to foreign innovators rises from 10% to 18%. By design, all countries benefit from this agreement, as shown in the first row of Table 2. The United States experiences the largest gains in consumption-equivalent units (0.85%), while China experiences the smallest gains (0.26%). This trade agreement yields both growth and level effects, as the BGP growth rate rises from 1.85% to 1.87%.

Table 2: Welfare Gains from Trade Agreement

	$\Delta\tilde{W}$**(USA)**	$\Delta\tilde{W}$**(China)**	g	$\tau_{\text{USA,China}}$	$\xi_{\text{China,USA}}$	$\xi_{\text{China,China}}$
Baseline	0.853%	0.262%	1.87%	0%	18%	25%

Notes: The table reports welfare gains, inclusive of the transition, computed from equation (28) for the US and China. The first two columns display the welfare gains in the US and China, respectively. The third column provides the BGP growth rate. The last three columns contain the values of the policy instruments selected within the agreement, namely tariffs, the royalty fee paid to foreign innovators, and the royalty fee paid to domestic innovators.

[18] Evaluating welfare along the transition allows us to address the issue that BGP to BGP gains may be overstated given firms need to make a costly investment (i.e, R&D or adoption) to benefit from higher long-term growth (see also Ravikumar, Santacreu, and Sposi, 2019; Perla, Tonetti, and Waugh, 2021).

[19] The model is solved using a Newton-type algorithm, which uses relaxation techniques. The details of the algorithm can be found in Juillard et al. (1996).

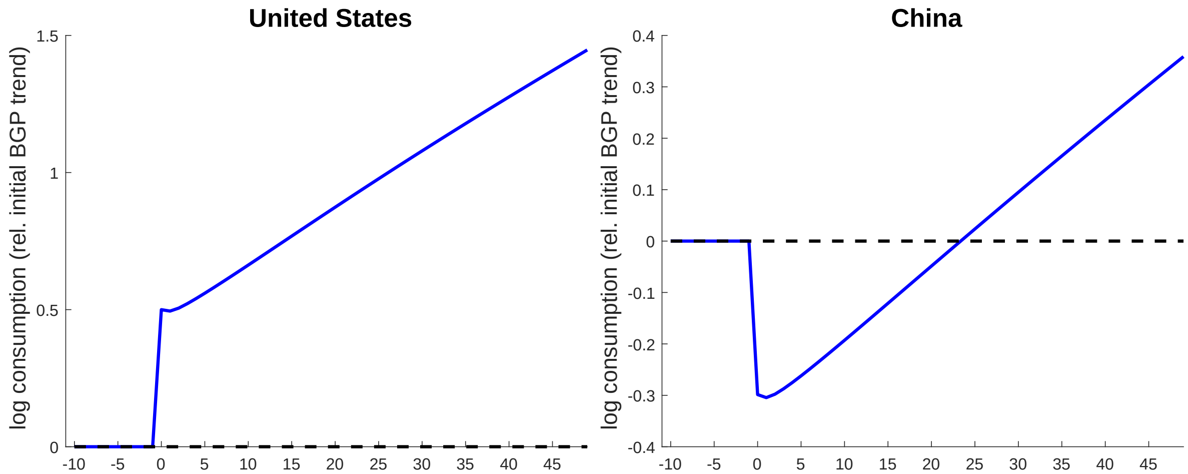
5.3.1 Dynamic effects of the trade agreement along the transition

Despite all countries experiencing positive gains overall, the way these accrue during the transition is heterogeneous across countries. I disentangle the short-term and long-term implications of the trade agreement by analyzing the transitional dynamics of consumption in the United States and in China following the shock. I then delve into the different components of welfare—income, R&D investment, and adoption investment—to understand what drives heterogeneous effects along the transition.

Welfare Figure 5 shows the evolution of consumption over time. Specifically, the figure plots the log of consumption relative to its initial BGP path, both in the United States (left panel) and in China (right panel). The solid lines in the two panels represent the log of consumption in the counterfactual—relative to the initial BGP consumption path. The horizontal lines at zero represent the initial BGP. The shock hits in period 1. From period -10 to period 0, the economy is in the initial BGP and consumption per capita grows at the rate of 1.85%. In period 1, China and the United States sign the trade agreement, which implies a jump in the level of consumption and a change in the growth rate. An improvement in IPR leads to a higher BGP growth rate of consumption in both the United States and China, which materializes in positive gains in the long run. However, consumption drops initially in China, implying short-term losses. The log of consumption crosses the horizontal dashed line more than 25 years after the initial shock, and China starts experiencing positive gains. The short-term losses in China are driven by the increase in royalty payments adopters need to make to foreign innovators when they improve IP protection. The trade liberalization helps to dampen the negative effect on consumption, as adopters and innovators benefit from access to a larger market. In the long run, the larger investment in R&D in China and the United States increases growth to 1.87% (Table 2), leading to long-term gains. The result is that it takes about 25 years for higher BGP growth to replace previously cheaper adoption.

In the United States, there are both short-term and long-term gains. Profits of both adopters and innovators go up, increasing output in the short and long run. The increase in output dominates the increase in R&D investment, driving consumption up. This channel is reinforced by a trade liberalization, as US final producers have access to cheaper intermediate products from China and the home trade share decreases.

Figure 5: Log of consumption



Notes: The figure plots the evolution of the log of consumption relative to its initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 50 periods after signing a trade agreement with IP provisions. The agreement is signed in period 1.

Next, I decompose consumption into its three components and evaluate the effects of the trade agreement on each of them along the transition. From the expression in equation (20):

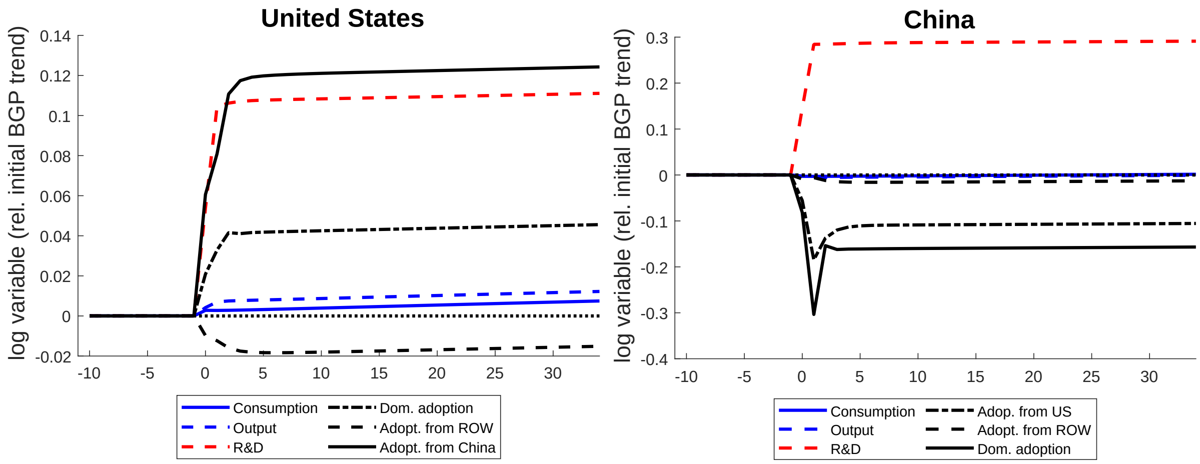
$$C_{nt} = Y_{nt} - H^r_{nt} - \sum_{i=1}^{M} H^a_{ni,t}.$$

Figure 6 illustrates the dynamics of each of these components, relative to their initial BGP (in logarithmic scale). All components exhibit the same growth rate. Consumption and output follow a similar trajectory following the agreement. In the United States, there is an initial output increase driven by higher innovation and adoption. China experiences an initial output decrease, which is later compensated by a higher growth rate.

The agreement leads to increased R&D investment, both in China and the United States. However, adoption displays different dynamics. Adoption increases in the United States (excluding adoption from the rest of the world) and decreases in China, reflecting a reallocation effect away from adoption toward innovation in the latter.

Next, I delve into the effect that the trade agreement has on key economic variables, namely innovation, adoption, growth and royalty payments.

Figure 6: Components of Welfare



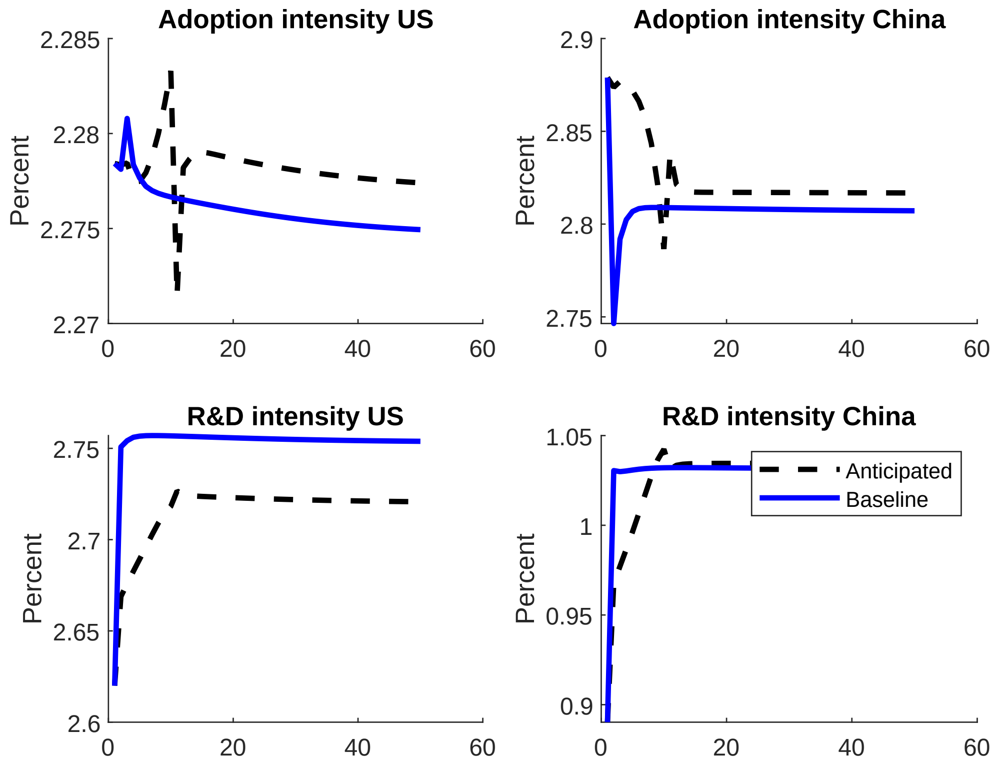
Notes: The figure plots the evolution of the log of consumption, output, R&D spending, and adoption spending, respectively, relative to their initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 20 periods after signing a trade agreement with IP provisions. The agreement is signed in period 1.

Growth, Innovation, and Adoption The trade agreement has a positive effect on R&D intensity in both countries through two channels. First, an increase in IPR enforcement increases the return to innovators, both in China and the United States, as innovators start receiving royalties for technologies that are adopted in China. Second, access to a larger market for Chinese exports increases domestic innovation in China. Both countries reach a higher level of R&D intensity in the counterfactual BGP.

Adoption in China is subject to two opposing forces: (i) the return to Chinese adopters decreases, as they now have to pay higher royalties, but (ii) adopters profit from exporting intermediate products that are produced with licensed technology. The net effect is a decline in adoption intensity, since there is a reallocation from adoption to innovation in China. This reallocation effect depends on the comparative advantage of innovation versus adoption.

As a result of more innovation worldwide, the BGP growth rate increases from 1.85% to 1.87%. The left panel of Figure 8 shows the evolution of productivity growth in the United States and in China after they sign the trade agreement. Both countries' productivity grows at the same 1.85% rate on the initial BGP. When the agreement is signed. In both the United States and China, the growth rate overshoots and then it converges smoothly toward the final BGP. Both countries reach a BGP growth rate of 1.87% on the counterfactual. Changes in growth rates are driven by the endogenous responses of innovation and adoption

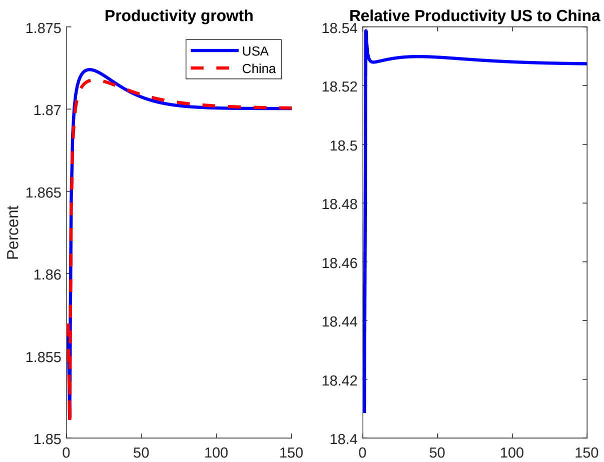
Figure 7: R&D and adoption intensity



Notes: The figure plots the evolution of adoption and R&D intensity in the United States and China during the 50 years following the signature of a trade agreement with IP provisions designed as Nash bargaining. Period 0 represents the initial BGP. The solid line represents the baseline agreement; the dashed line represents an anticipated agreement.

after changes in IP protection and tariffs. Moreover, the agreement increases inequality through a rise in relative productivity of the United States with respect to China, as the right panel of Figure 8 shows.

Figure 8: Growth rate of productivity

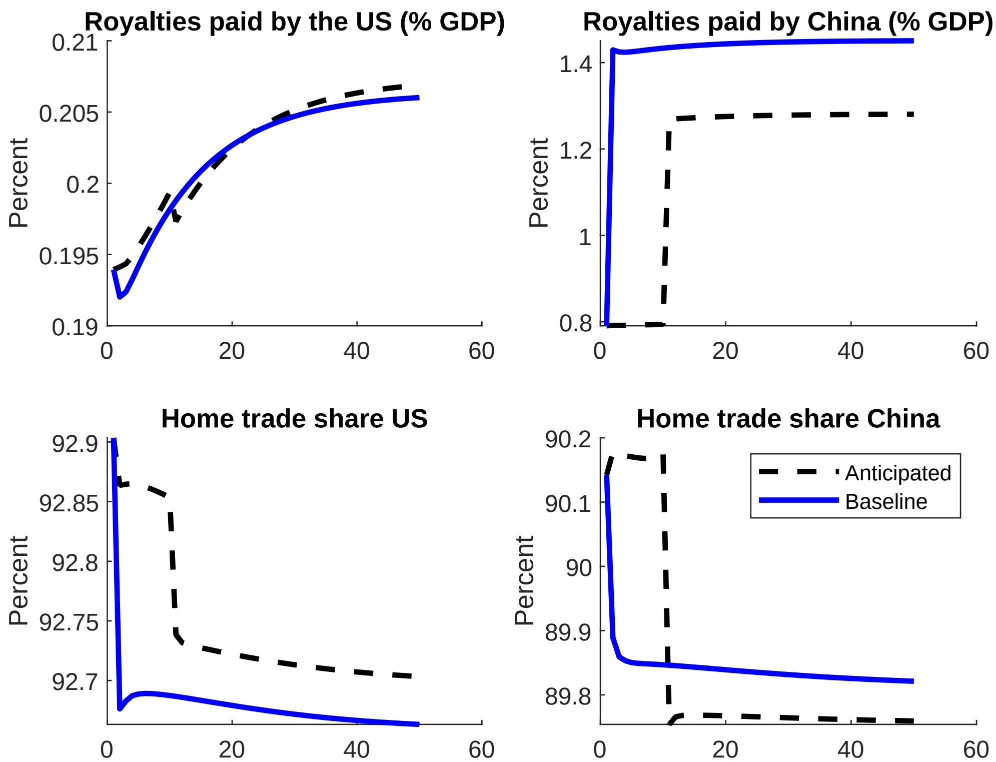


Notes: The figureplots the evolution of productivity growth in the United States and China (left panel) and relative productivity of the United States with respect to China (right panel), during the 150 years following the signature of a trade agreement with IP provisions designed as Nash bargaining. Period 0 represents the initial BGP.

Trade and Royalties The improvement in IP protection implies that China starts paying more royalties to domestic and foreign innovators for two reasons. Royalty payments from China to the United States increase, which is consistent with the evidence presented in Section 2 and Appendix A, offering external validation for the model. The United States also pays more royalties to China after signing the agreement, as China becomes more innovative. On net, the technology trade imbalance between the United States and China becomes wider.

The decrease in US tariffs on Chinese imports translates into a decrease in the US home trade share, resulting in productivity increases through the standard channel present in static trade models (see Figure 9).

Figure 9: Trade and royalty payments



Notes: The figureplots the evolution of royalty payments made by the United States and China and their home-trade shares during the 50 years following the signature of a trade agreement with IP provisions designed as Nash bargaining. Period 0 represents the initial BGP. The solid line represents the baseline agreement; the dashed line represents an anticipated agreement.

5.4 Understanding Interactions Between IP Reforms and Trade Policy

To better understand the main channels at play, I ask the following question: How do reforms in IPR impact the gains from trade liberalization? To address this question, I consider three alternative scenarios to the Nash bargaining problem defined in equation (36), which I refer to as the baseline agreement. First, I consider an alternative scenario in which the United States lowers import tariffs from China, but China does not improve its IPR. Second, I consider the case in which China improves its IP protection but does not benefit from lower tariffs. Third, I evaluate whether China has incentives to reform its domestic IPR unilaterally—i.e., China improves its domestic IPR but does not sign a trade agreement. In each of these cases, I assume the baseline agreement's outcome as given and then analyze the impact of modifying each instrument individually. Table 3 reports welfare gains and BGP growth rates in each scenario.

Table 3: Welfare Gains: Alternative scenarios

Counterfactual	$\Delta\tilde{W}$(USA) (%)	$\Delta\tilde{W}$(China) (%)	BGP Growth	$\tau_{\text{USA,China}}$	$\xi_{\text{China,USA}}$	$\xi_{\text{China,China}}$
Baseline	0.853%	0.262%	1.87%	0%	18%	25%
Only tariffs	-0.097%	0.167%	1.85%	0%	0%	0%
Only IPR	0.944%	0.085%	1.86%	5%	18%	25%
Unilateral IP reform	0.117%	0.307%	1.85%	5%	0%	25%
Nash equilibrium	0.174%	-0.528%	1.85%	20%	0%	25%
Shortsighted government	0.270%	0.354%	1.86%	1%	12%	25%
China deviates	0.096%	0.316%	1.85%	5%	0%	25%
China deviates (retal)	0.228%	-0.080%	1.85%	20%	0%	25%
Anticipated	0.651%	0.258%	1.86%	5%	16%	25%
Gradual	0.657%	0.277%	1.86%	5%	16%	25%

Notes: The table reports welfare gains, inclusive of the transition, computed from equation (28) for the US and China, as well as the BGP growth rate, and the terms of the agreement for various alternative scenarios: (1) Baseline, (2) only lower tariffs (only tariffs), (3) only IPR reform (both domestic and foreign), (4) unilateral improvement of domestic IPR (domestic IP reform without trade agreement), (5) Nash equilibrium, (6) a shortsighted government, (7) China deviates and the US increases tariffs to the initial level (5%), (8) China deviates and the US retaliates increasing tariffs to 20%, (9) anticipated policy, and (10) anticipated and gradual adjustment. In the cases (5), (6), (9), and (10), I recompute the Nash bargaining solution from equation (36). The first two columns display the welfare gains in the US and China, respectively. The third column provides the BGP growth rate. The last three columns contain the values of the policy instruments selected within the agreement, namely tariffs, the royalty fee paid to foreign innovators, and the royalty fee paid to domestic innovators.

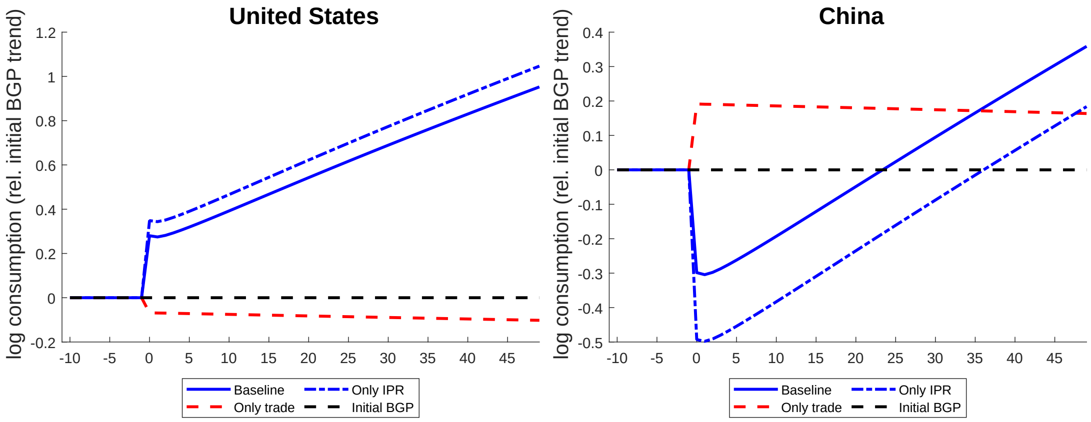
First, when the US eliminates tariffs on Chinese imports without China reforming its IP enforcement for both domestic and foreign IP, China experiences larger gains than in the baseline scenario, while the US experiences losses. Reduced tariffs on Chinese imports create a higher incentive for innovating and adopting technology, leading to increased profits and output due to access to a larger market all while avoiding royalties for foreign technology use. Conversely, increased competition from Chinese imports diminishes innovation incentives in the US. This, coupled with lost tax revenues and unfavorable terms of trade, leads to short-term losses in the US. Moreover, the absence of compensation for US innovators from their R&D efforts contributes to a long-term decline in innovation and global growth. Hence, tariff declines are crucial to incentivize improvements in IP enforcement of foreign firms and generate long-term growth.

Second, improvements in IPR that are not accompanied by a reduction in tariffs leave the BGP growth rate virtually unchanged. China experiences almost zero welfare gains (0.085% vs 0.262%). The main reason is that China experiences larger short-term losses than in the baseline scenario as China has to pay more royalties to foreign firms, but does not benefit from access to larger export markets (see Figure 10). Because the BGP growth rate barely moves, it takes longer for these losses to be compensated by a higher growth rate, yielding very low gains in China. The United States experiences larger short-term and long-term gains. Innovators receive more royalty payments, but the government does not give up tariff revenues or controlling its terms of trade in exchange for more royalty payments.

Finally, I examine whether China has incentives to reform its domestic IP enforcement unilaterally without participating in a trade agreement. In this case, welfare gains for China are larger than in the baseline scenario, albeit at the expense of the United States, which sees lower gains. By abstaining from the agreement, China foregoes the potential for lower tariffs but avoids incurring a higher cost for adopting foreign technologies. Throughout the transitional phase, the positive effect of lower US tariffs is outweighed by the negative impact of incurring higher adoption costs, and China experiences short-term gains (see Figure 11).

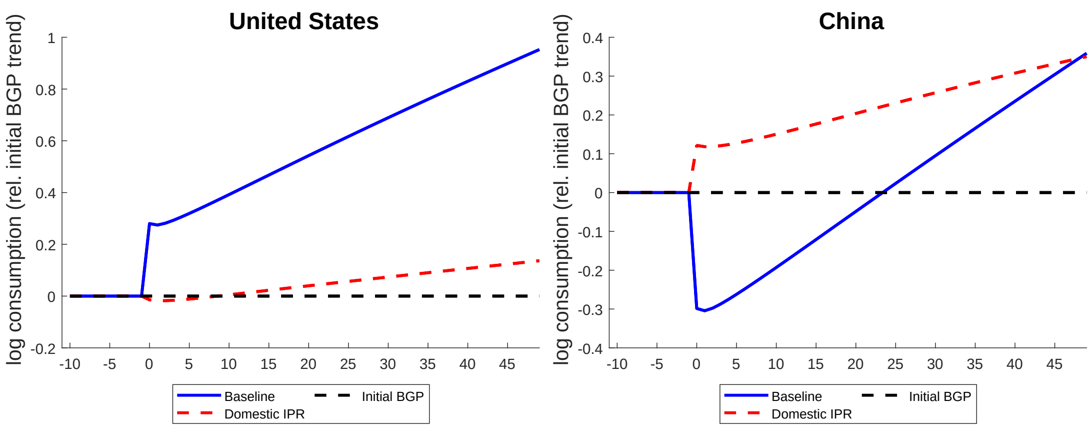
The results highlight several insights. First, China's drive to improve its domestic IP enforcement is internally motivated and does not necessarily depend on external incentives (i.e., lower tariffs through a trade agreement). Moreover, participation in a trade agreement can act as a stimulus for China to strengthen its protection of foreign IP through lower tariffs. While tariffs predominantly produce short-term impacts, they can be used as a tool

Figure 10: Log of consumption relative to initial BGP trend: Trade policy and IP reforms



Notes: The figure plots the evolution of the log of consumption relative to its initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 50 periods after signing an agreement. The agreement is signed in period 1. The solid line represents the baseline trade agreement with IP provisions. The dashed line represents the case in which China improves IPR, but there is not a reduction in US tariffs. The dash-dotted line represents the case in which there is a reduction in US tariffs but China does not improve its IPR.

Figure 11: Log of consumption relative to initial BGP trend: Unilateral IP reform



Notes: The figure plots the evolution of the log of consumption relative to its initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 50 periods after signing an agreement. The agreement is signed in period 1. The solid line represents the baseline trade agreement with IP provisions. The red dashed line represents the case in which China unilaterally improves domestic IP without being part of a trade agreement.

for incentivizing IP reforms or discouraging departures from the agreement, especially when it comes to foreign IP.

5.5 Revisiting the Main Assumptions of the Trade Agreement

Next, I revisit some of the assumptions made in the Nash bargaining problem defined in equation (36). First, I compare the cooperative nature of the baseline agreement with the uncooperative Nash equilibrium solution, where each country optimizes its strategy based on its trading partner's actions. Second, in the baseline agreement, governments prioritize welfare maximization and are not concerned about short-term losses. I explore an alternative scenario where a shortsighted government prioritizes short-term gains. Third, the agreement assumes perfect enforcement and commitment. I investigate a situation where China deviates from the agreement, and the US can respond with higher tariffs. Finally, I revisit the assumption that the agreement is unanticipated and enters into force immediately. Here, I consider two alternative cases: one where the agreement is anticipated but enters into force immediately and another that is anticipated but involves a gradual adjustment of instruments after the agreement. The results of these alternative scenarios are reported in Table 3.

Cooperative vs uncooperative trade agreement I contrast the outcomes of a Nash bargaining agreement, where countries cooperate, with a Nash equilibrium scenario where each country independently selects its optimal response based on the given response of the other country.

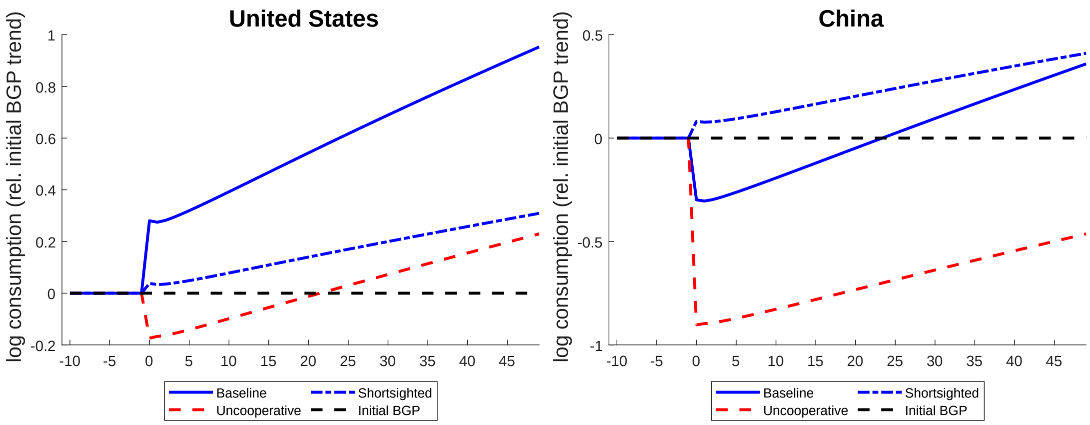
The uncooperative solution consists of the US increasing tariffs to 20% and China improving only domestic IP enforcement. Specifically, the foreign royalty fee stays as in the baseline (10%), whereas the domestic royalty fee increases to 25%.[20] The implications for welfare are significant. In the baseline scenario, both the US and China experience welfare gains, with US welfare increasing by 0.853% and China's by 0.262%. The Nash equilibrium presents a less optimistic picture, with US welfare increasing by a smaller magnitude (0.174%) and China experiencing losses of -0.528%. The BGP growth rate is lower at 1.85%. These findings are consistent with China's motivation to improve its enforcement of IPR on domestic technologies. The United States, on the other hand, leans toward imposing higher tariffs to counter foreign competition, particularly from countries with weak IP protection. It

[20] I find that the Nash equilibrium in this game is unique through a numerical analysis.

is noteworthy that the US preference for higher tariffs diminishes as the exporting country's IP enforcement strengthens.

In summary, the cooperative solution yields more favorable outcomes, resulting in higher welfare gains for both countries. Agreeing on tariffs and IP enforcement during negotiations can potentially lead to a mutually beneficial economic path, in contrast to the Nash equilibrium where non-cooperative actions result in suboptimal outcomes.

Figure 12: Log of consumption relative to initial BGP trend: Uncooperative and shortsighted governments



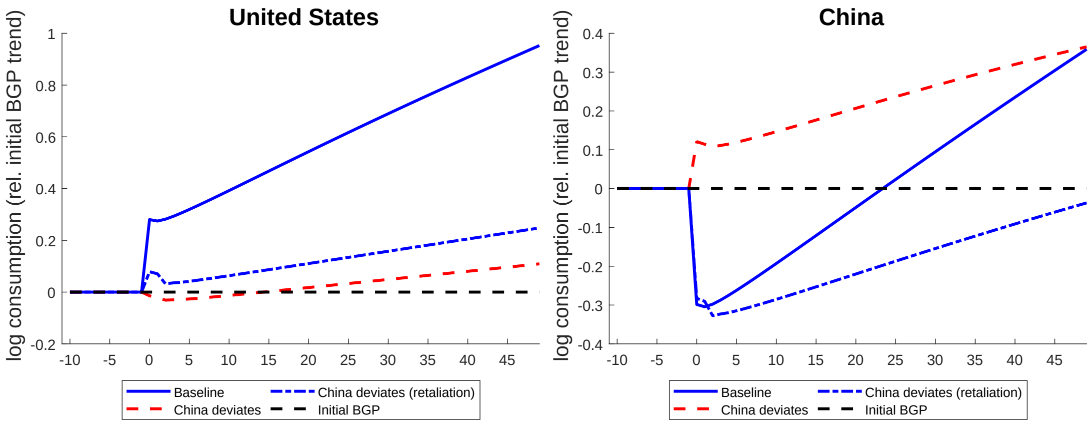
Notes: The figure plots the evolution of the log of consumption relative to its initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 50 periods after signing an agreement. The agreement is signed in period 1. The solid line represents the baseline trade agreement with IP provisions. The red dashed line represents the uncooperative case. The blue dotted line represents a shortsighted government that wants to avoid short-term losses.

Welfare-maximizing versus Shortsighted Government The trade agreement in the baseline scenario has been designed by a welfare-maximizing government that chooses tariffs and level of IP protection to maximize overall welfare, without paying attention to the short run. By signing such an agreement, both the United States and China gain overall, but China suffers short-term losses. Thus, the agreement may not be attractive to a government that wants to avoid such short-term losses. Here, I consider the design of a trade agreement made by a government with short-term objectives (i.e., a shortsighted government). Specifically, I assume the government in each country has a lower discount factor than the consumer (i.e., 0.96 vs 0.98). I then compute the level of tariffs and quality of IP enforcement that solve the bargaining problem in equation (36), where welfare gains are discounted at the government's discount factor. The new agreement consists of a reduction in US tariffs on Chinese imports of 80%, full improvement of domestic IPR in China, and an increase in China's foreign royalty fee from 10% to 12%. Compared with the baseline agreement, both countries have positive gains in the short run (see Figure 12). However, welfare gains in the United States are now lower (see Table 3). A shortsighted government can avoid short term losses at the expense of lower BGP growth and lower long-term gains.

China deviates The baseline trade agreement is premised on commitment. Nevertheless, China might find it tempting to deviate from the agreement as a strategy to evade short-term losses. In this section, I study the case in which China deviates from the agreement two periods after it enters into force—China chooses to maintain royalties paid to domestic innovators at 25% while reducing foreign royalties from the agreed-upon rate of 18% to the initial rate of 10%—considering two different responses from the US: one where the US raises tariffs back to their initial levels (i.e., from 0% to 5%) and another where the US retaliates by increasing tariffs significantly (from 0% to 20%). Under the first response, China experiences gains both in the short run and in the long run, with overall gains exceeding those in the baseline scenario, even if the United States responds by reverting to the initial tariff rate of 5%. During this phase, the US experiences short-term losses for several periods and overall reduced gains. Instead, if the United States chooses to retaliate by increasing tariffs to 20%, China faces overall losses and considerably larger short-term losses than if it had adhered to the original agreement (see Figure 13 and Table 3). Consequently, a credible threat of US tariff retaliation may provide China with an incentive to keep the original agreement, rendering it sustainable.

Anticipatory and gradual effects The baseline trade agreement was unanticipated and entered into force immediately after signing it. Here, I consider two alternative scenarios that help us understand the role of the timing at which the different agreements enter into force: anticipation and gradual adjustment. In the anticipation case, countries engage in negotiations for a trade agreement today, set to take effect in 10 years with perfect foresight, leading to anticipatory effects. In the gradual adjustment scenario, negotiations today result in a trade agreement that becomes effective in 5 years with a slower change in the instruments. After 10 years, these instruments reach their final value and remain

Figure 13: Log of consumption relative to initial BGP trend: China deviates

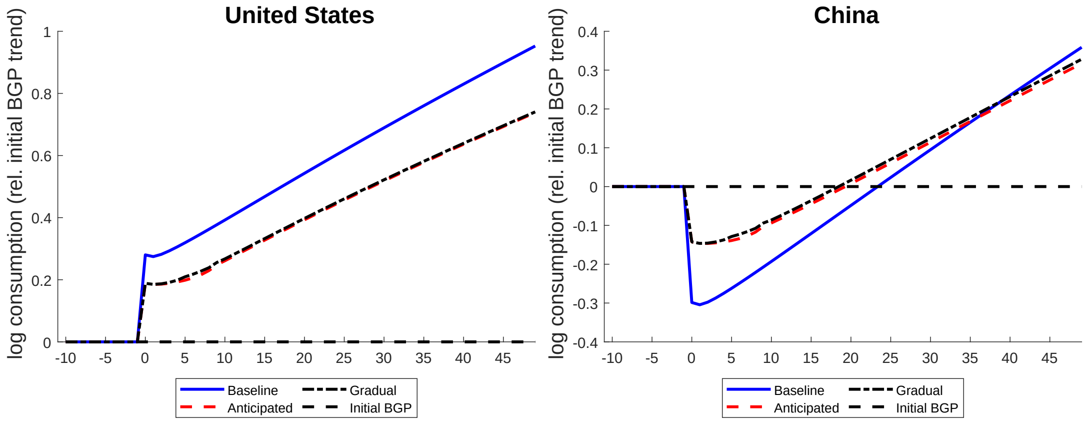


Notes: The figure plots the evolution of the log of consumption relative to its initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 50 periods after signing a trade agreement with IP provisions in the baseline (solid line), when China deviates 2 periods after the agreement entering in force and the US goes back to the initial tariffs of 5% (red dashed line), and when China deviates 2 periods after the agreement entering in force and the US retaliates imposing high tariffs of 20% (blue dotted line). The agreement is signed in period 1 and enters in force in period 11.

at those values permanently, introducing additional dynamics to the model. As we can see in Figure 7, anticipatory effects lead to more gradual adjustments in innovation and adoption, driven by forward-looking decisions, than the unanticipated agreement. Agents react today, anticipating changes in tariffs and IP enforcement. Moreover, Figure 14 shows that consumption converges to the new BGP value more gradually than under the baseline agreement.

The findings indicate that policy decisions are influenced by anticipatory and gradual effects since forward-looking agents are involved, which has welfare implications. Notably, in the case of China, a gradually anticipated trade agreement surpasses the baseline agreement in terms of welfare gains. Both the anticipated and gradual agreements lead to reduced short-term losses for China and ultimately higher overall gains, partly due to the final BGP growth rate matching that of the baseline scenario. Lower short-term losses, combined with the higher BGP growth rate, result in increased overall gains.

Figure 14: Log of consumption relative to initial BGP trend: The role of anticipation



Notes: The figure plots the evolution of the log of consumption relative to its initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 50 periods after signing a trade agreement with IP provisions in the case of unanticipated trade agreement (blue solid line), anticipated 10 periods earlier (red dashed line), or anticipated and gradual agreement (black dotted-dashed line). The agreement is signed in period 1 and enters in force in period 11.

5.6 What characterizes the trade agreement?

The specific terms of a trade agreement resulting from Nash bargaining negotiations are contingent upon various factors. I conduct sensitivity analysis to identify the key characteristics of the negotiating countries that influence the outcomes of the baseline agreement. Specifically, I examine the influence of four critical parameters: (i) the bargaining power of the negotiating parties, (ii) the innovation efficiency in China, (iii) the initial level of tariffs in the US, and (iv) the initial level of IP protection in China. In each of these cases, I impose the new value of each parameter without recalibrating the model and then solve for the Nash bargaining solution in equation (36). The results are presented in Table 4.

The bargaining power Here, I analyze the role of the bargaining power of the parties involved in the agreement. If the US has all the bargaining power, the trade agreement would consist of an 80% reduction of tariffs and an increase in the royalty fee paid by China to the US from 10% to 25%. The welfare gains for the United States increase significantly to 1.604%, while China experiences virtually zero gains (0.004%). Instead, if China has all the bargaining power, the agreement would involve China only reforming domestic IPR and the US removing all tariffs.

Table 4: Nash Bargaining Under Different Parameter Values

	$\Delta\tilde{W}$**(USA)**	$\Delta\tilde{W}$**(China)**	$\tau_{\text{USA,China}}$	$\xi_{\text{China,USA}}$	$\xi_{\text{China,China}}$
Baseline	0.853%	0.262%	0%	18%	25%
Different Parameter Values					
$\rho = 1$	1.604 %	0.004%	4%	25%	25%
$\rho = 0$	0.022%	0.477%	0%	0%	25%
Low innov efficiency	0.422%	0.091%	0%	15%	25%
Low tariffs	0.721%	0.189%	0%	16%	25%
High tariffs	1.391%	0.466%	0%	25%	25%
Low IPR	1.320%	0.312%	0%	15%	25%
Perfect domestic IPR	0.165%	0.120%	0%	11%	0%

Notes: The table reports welfare gains for the United States and China from signing a trade agreement with IP provisions under different initial conditions: (i) baseline, (ii) different bargaining power, (iii) lower innovation efficiency in China, (iv) lower US tariffs, (v) higher US tariffs, (vi) lower IPR in China, and (vii) perfect IPR on domestic IP. Welfare gains correspond to those from a Nash bargaining agreement that satisfies the restrictions in equation (27). Columns 4-6 report optimal tariffs and quality of IP enforcement from signing the agreements under each alternative parameterization.

These findings reveal different preferences: China leans towards lower tariffs and strengthened domestic IP enforcement, whereas the United States benefits more when China improves both foreign and domestic IP protection while eliminating tariffs. Tariffs serve as an instrument to incentivize China to enhance its IP protection for foreign IP.

The innovation efficiency in China China's innovation efficiency, which pins down the initial level of R&D intensity, plays a crucial role in determining the extent of IP improvement agreed upon by China during Nash bargaining negotiations. If China's innovation efficiency is set to be one third of that from its calibrated value, the optimal agreement involves a lower improvement of IP enforcement toward foreign firms, resulting in lower welfare gains in both countries. In the extreme case, if China's innovation efficiency is exceedingly low, a viable trade agreement wherein China commits to enhancing its IPR may not materialize. Hence, countries need a minimum innovation efficiency to be willing to enter an agreement that involves improving their IP enforcement on foreign technologies.

The initial level of tariffs in the US When initial tariffs are low, China stands to gain less from the tariff removal aspect of the trade agreement. With initial US tariffs being one half of their initial level, the trade agreement would involve a lower improvement of IP enforcement toward foreign firms and lower gains everywhere.

Conversely, when the US starts with high initial tariffs, the dynamics of the trade agreement change. The potential gains for China from the removal of these high tariffs are substantial. In this scenario, the attractiveness of reducing US tariffs dominates, and China is more willing to make concessions, including significant improvements in IP enforcement towards foreign firms. Both countries, therefore, experience higher overall gains. The rationale here is that the substantial reduction in US tariffs provides a strong incentive for China to reciprocate with concessions in IP enforcement, as the combined effect of reduced tariffs and improved IP protection enhances the overall attractiveness of the trade agreement.

The initial level of IP protection in China Here, I investigate the role of the initial level of IP protection in China. If the US and China sign the trade agreement outlined in the baseline scenario, but with the initial level of IP protection in China being one-half of that in the baseline scenario (i.e., $\eta_{\text{China}} = 0.2$), the agreement would result in a substantially smaller improvement of IP enforcement on foreign IP. In this case, the foreign royalty fee would increase from 10% to 16%. If the initial level of IP enforcement is too low, there may not exist an agreement that both parties want to sign, since the US may not be willing to give up tariffs for a small increase in royalty payments. Finally, if China has perfect domestic IPR initially but weak IP protection on foreign IP, the proposed trade agreement would entail the removal of US tariffs, accompanied by only a marginal improvement in foreign IPR. Specifically, the royalty fee is expected to see a modest increase from 10% to 11%. In such a context, if China begins with a state of perfect IPR enforcement, its motivation to participate in the trade agreement diminishes, given the limited gains in foreign IPR improvement.

In summary, the results highlight the factors influencing China's openness to improving how it protects foreign and domestic IP. These factors include how much bargaining power each side has, how innovative China is initially, the initial level of US tariffs on Chinese imports, and China's initial IP protection rules. Importantly, China has a consistent reason to make sure its own IP is well-protected, whereas the US can use tariffs strategically to encourage China to improve IP protection for foreign technologies as well. This improvement in protecting foreign IP can lead to higher growth rates on the new BGP. Therefore, the nature and terms of the trade agreement, as well as a country's inclination to engage in such agreements, are contingent on the extent to which a low-enforcement country lags behind the technology frontier. This measurement takes into account two crucial factors: the country's innovation efficiency and the level of IPR protection. The more distant a country is from the technology frontier, the more critical these factors become in shaping the trade agreement landscape and its participants' willingness to participate.

6 Final Remarks

This paper has developed a quantitative theory to analyze the dynamic trade-offs faced by countries signing bilateral trade agreements with IP provisions. Thus, it addresses the gap between existing quantitative models of trade and growth and political-economic theories of trade agreements. The paper emphasizes the importance of conducting quantitative analysis that takes into account transitional dynamics. In the short run, trade agreements with IP provisions have significant distributional effects. Thus, it becomes crucial to distinguish between short-term and long-term effects, highlighting the substantial impact of such agreements on technology transfer, as measured through royalty payments. Finally, the paper conducts a comprehensive analysis, with a focus on the role of various parameters and data moments in shaping the outcomes of these trade agreements.

The results from the analysis indicate that developing countries have an incentive to unilaterally improve their protection on domestic IP. However, to encourage them to also improve protection for foreign IP, they need lower tariffs from developed countries. While improvements in foreign IP protection initially result in short-term losses for developing countries, these are offset by a subsequent higher BGP growth rate several years after signing the agreement. Comparison with the uncooperative solution reveals gains from cooperation. Finally, an anticipated and gradual agreement proves beneficial, especially for developing countries with low IP enforcement.

The main results of the paper open up a multitude of questions to be addressed in future work. The results have implications for optimal trade and IP policy, as the interactions between the two suggest that trade and IP policies can be used simultaneously to reach a first-best solution. Moreover, the analysis abstracts from imperfect enforcement of trade agreements and lack of commitment. In the context of the cooperative baseline trade agreement, where countries are assumed to commit to agreed policies, the issue of credible commitment becomes crucial, particularly when there are short-term losses that may tempt countries to deviate from their commitments. To address this challenge, the United States can employ a strategy of credible commitment by signaling its willingness to impose high tariffs as a form of retaliation against non-compliance, in this case, China's failure to pay royalties. The efficacy of this commitment hinges on its credibility, meaning that China must believe that the US will genuinely follow through with high tariffs in response to deviations. This credible commitment creates a disincentive for China to deviate from the agreement, as the prospect of punitive tariffs may deter such behavior. Moreover, the concept of contingency plans, where the US has pre-established strategies involving high tariffs to counter deviations, further reinforces the credibility of the commitment. While this approach does not require solving for a formal contract, it offers an intermediate solution to the time inconsistency problem by striking a balance between short-term enforcement costs and the long-term benefits of trade cooperation. Finally, the agreement does not address uncertainty. Decisions regarding IP investments are susceptible to geopolitical, technological, and market uncertainties (Handley and Limão, 2017). I leave these questions for future research.

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APPENDIX

A Empirical Analysis: Robustness

Next, I conduct a comprehensive econometric analysis to evaluate the effect of bilateral RTAs with IP provisions on technology transfer, measured as royalty payments, between countries. I follow Baier and Bergstrand (2007) and estimate a reduced-form gravity regression with exporter-time, importer-time, and country-pair fixed effects to identify the role of IP chapters included in RTAs. In particular, I estimate the following specification:

$$RP_{in,t} = \exp\left(\sum_{k\in\{T,NT\}} \mathrm{RTA}^{k}_{in,t} + S_{nt} + F_{it} + fe_{in}\right) * u_{int} \tag{A.1}$$

with $\mathrm{RTA}^{k}_{in,t}$, an RTA with technology provisions (specifically, IP provisions) when $k = \mathrm{T}$ and without such provisions when $k = \mathrm{NT}$, as classified by Martínez-Zarzoso and Chelala (2021), S_{nt} exporter-time, F_{it} importer-time, and fe_{in} country-pair characteristics. I estimate equation (A.1) using PPML methods as recommended by Baier and Bergstrand (2007); Silva and Tenreyro (2006); Yotov et al. (2016); Zylkin (2018). This estimation approach has several advantages. First, as Baier and Bergstrand (2007) show, including time-invariant bilateral dummies allows me to control for potential endogeneity of RTAs (if they are not arbitrarily assigned) as these dummies control for all unobserved heterogeneity related to each country-pair. Second, PPML methods can account for zeros in the dependent variable and can deal with heteroskedasticity of the error term in the gravity equation.

I run the specification for the whole sample of countries in Table A.1 and for four groups of countries classified according to their development level in Table A.2 (N corresponds to North and S corresponds to South).[21] RTAs include those with technology and non-technology provisions, as well as TRIPS, in order to evaluate whether more-recent RTAs have an effect on technology transfer beyond that of TRIPS. The first two columns focus on the effect on royalty payments, whereas the last two columns focus on the effect on international trade. There are two sources of identification in the regression analysis: (i) observations from before and after an agreement enters into force, and (ii) country-pairs

[21] I use GDP per capital data to classify a country as North or South. Countries belong to South if their GDP pc was below 12,500 USD in 2012.

never signing any agreement during the period of analysis.

Table A.1 shows that RTAs with technology provisions have a positive and statistically significant effect on bilateral royalty payments. That is, country-pairs that form RTAs that contain IP chapters share more technology. In this case, the results suggest that signing RTAs with IP provisions increases royalty payments between the countries by 19%.[22] RTAs without technology provisions and TRIPS do not have a significant effect. In the case of international trade, both types of RTAs (with and without IP provisions) have a positive and statistically significant effect as in Martínez-Zarzoso and Chelala (2021), but it is smaller than in the case of royalty payments.

Table A.1: The effect of RTAs with IP provisions on international technology licensing

	Royalties		Trade	
RTA tech	0.175***	-0.408***	0.0396**	-0.0507
	(0.0349)	(0.0993)	(0.0123)	(0.0375)
RTA notech	-0.00852	0.00390	0.0918***	0.0942***
	(0.0728)	(0.0726)	(0.0196)	(0.0196)
trips	0.0805	0.0819	0.0206	0.0208
	(0.0933)	(0.0940)	(0.0325)	(0.0325)
RTA tech (patents/IP)		0.612***		0.0975*
		(0.105)		(0.0392)
N	43,398	43,398	44,100	44,100
pseudo R^2	0.74	0.74	1.00	1.00

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The table captures the effects of RTAs with technology provisions (RTA tech) and without technology provisions (RTA no tech) on bilateral royalty payments (first two columns), and bilateral trade (last two columns) between 1995 and 2012. It controls also for a dummy variable capturing whether the countries are part of TRIPS. The regression is done with PPML methods and it includes exporter time, importer time, and bilateral fixed effects. In columns 2 and 4 it isolates the effect of technology provisions related to patents and IP (RTA tech (patents/IP)).

Many of the deep trade agreements form between advanced economies and developing countries. These agreements are appealing to firms in developed countries because they

[22] $[exp(\beta) - 1] * 100$.

have a strong interest in protecting and strengthening their IPR in the developing countries where they conduct business. In Table A.2, I report results from running the regression in equation (A.1) considering 4 groups of countries: (i) royalty payments from South to North (NS), (ii) from North to North (NN), (iii) from North to South (SN), and (iv) from South to South (SS). The results show that RTAs containing IP provisions have a positive and statistically significant impact on royalty payments, specially in two scenarios. Firstly, when two advanced economies sign the agreement (NN), there is an observable increase in royalty payments. Second, when a developed and a developing economy sign an agreement, with the developing economy paying royalties to the developed one (NS), we also observe a significant rise in royalty payments. These findings suggest that RTAs with technology provisions lead to more technology licensing from advanced economies (North) to developing economies (South). TRIPS plays a pivotal role in royalty payments in agreements between advanced economies and between advanced economies and developing economies for royalty flows from North to South (SN). This is different from RTAs with tech provisions that matter more for royalty payments from South to North.

Technology-related RTAs could take several forms: technology cooperation, R&D cooperation or patents and IP protections. The conjecture in the empirical analysis is that it is provisions related to patents and IP protection that matter for technology transfer through licensing. Tables A.1 and A.2 (specifically, columns 2 and 4) present results when we consider patents and IP provisions as integral components of RTAs with technology-related provisions. These findings align consistently with those presented in Table A.1. Notably, provisions related to patents and IP exhibit a positive and statistically significant impact on royalty payments. Furthermore, when we factor in patents and IP provisions alongside other types of technology provisions, the outcomes emphasize that the provisions primarily influencing technology licensing are those associated with patent protection. This observation is consistent with the mechanisms outlined in the model. These results extend to international trade flows, aligning with the findings in Martínez-Zarzoso and Chelala (2021).

In summary, RTAs with IP provisions, particularly those targeting patent protection, emerge as an important channel for technology transfer from advanced economies to developing economies. These findings align with the model presented in the paper and offer external validation of the main measure used to study the impact of IP enforcement within the framework of trade agreements, which is royalty payments.

Table A.2: The effect of RTAs with IP provisions on international technology licensing by level of development

	(1) Royalties	(2) Trade	(3) Royalties	(4) Trade
RTA tech NS	0.136**	0.0646**	-0.541***	-0.0285
	(0.0514)	(0.0212)	(0.110)	(0.0351)
RTA tech NN	0.311***	-0.227***	0.309*	-0.376**
	(0.0507)	(0.0275)	(0.129)	(0.131)
RTA tech SN	0.0588	0.0960***	-0.314	0.152*
	(0.0987)	(0.0245)	(0.188)	(0.0639)
RTA tech SS	-0.111	0.0852***	0.897	0.112
	(0.146)	(0.0198)	(0.487)	(0.0676)
RTA notech NS	-0.284*	0.149***	-0.274*	0.152***
	(0.128)	(0.0382)	(0.126)	(0.0381)
RTA notech NN	0	0	0	0
	(.)	(.)	(.)	(.)
RTA notech SN	0.207	0.0797*	0.211	0.0788*
	(0.147)	(0.0400)	(0.148)	(0.0400)
RTA notech SS	0.0539	0.103***	0.0699	0.103***
	(0.0991)	(0.0235)	(0.0994)	(0.0235)
trips NS	0.0370	-0.0164	0.0385	-0.0162
	(0.0995)	(0.0322)	(0.100)	(0.0322)
trips NN	1.159***	0.180***	1.158***	0.180***
	(0.282)	(0.0464)	(0.282)	(0.0464)
trips SN	1.574***	0.109*	1.574***	0.109*
	(0.328)	(0.0451)	(0.329)	(0.0451)
trips SS	0.227	0.0000591	0.231	0.000293
	(0.207)	(0.0329)	(0.208)	(0.0328)
RTA tech (Patents/IP) NS			0.718***	0.103*
			(0.120)	(0.0401)
RTA tech (Patents/IP) NN			0.00299	0.170
			(0.141)	(0.133)
RTA tech (Patents/IP) SN			0.408	-0.0591
			(0.215)	(0.0681)
RTA tech (Patents/IP) SS			-1.006*	-0.0265
			(0.504)	(0.0700)
N	43,398	44,100	43,398	44,100
pseudo R^2	0.74	1.00	0.74	1.00

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The table captures the effects of RTAs with technology provisions (RTA tech) and without technology provisions (RTA no tech) on bilateral royalty payments (first two columns), and bilateral trade (last two columns) between 1995 and 2012. It controls also for a dummy variable capturing whether the countries are part of TRIPS. The regression is done with PPML methods and it includes exporter time, importer time, and bilateral fixed effects. It considers bilateral flows using 4 groups of countries: (i) royalty payments from South to North (NS), (ii) from North to North (NN), (iii) from North to South (SN), and (iv) from South to South (SS). In columns 2 and 4 it isolates the effect of technology provisions related to patents and IP.

B Derivations

Final Good Price Start from equation (3):

$$Y_{nt} = \left(\sum_{i=1}^{M} \Omega_i^{\sigma-1} T_{it} x_{ni,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}. \tag{B.1}$$

From the demand of intermediate goods,

$$Y_{nt} = \left(\sum_{i=1}^{M} \Omega_i^{\sigma-1} T_{it} \left(\left(\frac{\bar{m} W_{it} d_{ni} (1+\tau_{ni,t})}{P_{nt}} \right)^{-\sigma} Y_{nt} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{B.2}$$

From here,

$$P_{nt} = \left(\sum_{i=1}^{M} \Omega_i^{\sigma-1} T_{it} \left(\bar{m} W_{it} d_{ni} (1+\tau_{ni,t}) \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}. \tag{B.3}$$

Trade share

$$\pi_{in,t} = \frac{X_{in,t}}{\sum_{i=1}^{M} X_{in,t}} = \frac{\Omega_n^{\sigma-1} T_{nt} \left(\frac{\bar{m} W_{nt} d_{in} (1+\tau_{in,t})}{P_{it}} \right)^{1-\sigma} P_{it} Y_{it}}{\sum_{k=1}^{M} \Omega_k^{\sigma-1} T_{kt} \left(\frac{\bar{m} W_{it} d_{ik} (1+\tau_{ik})}{P_{it}} \right)^{1-\sigma} P_{it} Y_{it}}, \tag{B.4}$$

where $X_{in,t}$ is country i's expenditure on goods from country n.

From here,

$$\pi_{in,t} = \frac{\Omega_i^{\sigma-1} T_{it} \left(W_{nt} d_{in} (1+\tau_{in,t}) \right)^{1-\sigma}}{\sum_{k=1}^{M} T_{kt} \left(W_{it} d_{ik} (1+\tau_{ik}) \right)^{1-\sigma}}. \tag{B.5}$$

The home trade share is then

$$\pi_{nn,t} = \frac{\Omega_n^{\sigma-1} T_{nt} \left(W_{nt} \right)^{1-\sigma}}{P_{nt}^{1-\sigma}}. \tag{B.6}$$

ACR formula Relative wages take the ACR formula

$$\frac{W_{nt}}{P_{nt}} = \frac{1}{\bar{m}} \left(\frac{T_{nt}}{\pi_{nn,t}} \right)^{\frac{1}{\sigma-1}}. \tag{B.7}$$

From this formula, the growth rate of real wages in the steady state is $\frac{1}{\sigma-1} g_T$.

Profits of intermediate producers In each country i there are $T_{it} = \sum_{n=1}^{M} A_{in,t}$ intermediate producers (as many as adopted technologies). Each intermediate producer makes $\frac{\Pi_{it}}{T_{it}}$ in profits. Profits made with each adopted technology are composed of profits from the domestic and export market:

$$\Pi_{it} = \sum_{m=1}^{M} \frac{\pi_{mi,t}}{1+\tau_{mi}} P_{mt} Y_{mt} - W_{it} L_{it}, \tag{B.8}$$

where $\sum_{m=1}^{M} \frac{p_{mi} x_{mi}}{1+\tau_{mi}} - W_{it} L_{it} = \sum_{m=1}^{M} \bar{m} W_i d_{mi}(1+\tau_{mi}) l_{mi} / (d_{mi}(1+\tau_{mi}) - W_{it} L_{it} = (\bar{m} - 1) W_{it} L_{it}$.

Then,

$$\Pi_{it} = (\bar{m} - 1) W_{it} L_{it}.$$

What are the profits of all the firms in the economy?

- Innovators:
$$\sum_{i=1}^{M} RP_{in,t} - P_{nt} H_{nt}^{r}.$$

- Adopters and intermediate producers:
$$-P_{nt} \sum_{i=1}^{M} H_{in,t}^{a} + \Pi_{nt} - \sum_{i=1}^{M} RP_{ni,t},$$

  where royalties are given by

$$RP_{in,t} = \frac{A_{in,t}}{T_{it}} \chi_{in,t} \Pi_{it}.$$

Note that in the BGP (solving equations 8 and 11)

$$\frac{A_{in}}{T_i} \chi_{in,t} \Pi_i = \frac{\varepsilon_{in}}{\varepsilon_{in} + g} \chi_{in,t} \lambda_n \left(\frac{H_n^r}{Y_n} \right)^{\beta_r} \frac{T_n}{T_i} \Pi_i.$$

In equilibrium, $\Pi_i = (\bar{m} - 1) W_i L_i$.

C Equations of the Model

Endogenous variables

$$\{Y_{nt}, P_{nt}, W_{nt}, C_{nt}, \Pi_{nt}, R_t, Z_{nt}, H^r_{nt}, T_{nt}, H^a_{in,t}, A_{in,t}, x_{in,t},$$

$$p_{in,t}, \pi_{in,t}, V_{nt}, J^{\text{innov}}_{in,t}, V^{\text{innov}}_{in,t}, J^{\text{adopt}}_{in,t}, V^{\text{adopt}}_{in,t}, \varepsilon_{in,t}, RP_{in,t}\}$$

Equations:

Resource constraint

$$Y_{nt} = C_{nt} + H^r_{nt} + H^a_{nt}$$

Prices

$$P_{nt} = \left(\sum_{i=1}^{M} \Omega_i^{\sigma-1} T_{it} p_{ni,t}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

Price intermediate goods

$$p_{in,t} = \bar{m} W_{nt} d_{in} (1 + \tau_{in,t})$$

Demand intermediate goods

$$p_{in,t} x_{in,t} = \left(\frac{\bar{m} W_{nt} d_{in} (1 + \tau_{in,t})}{P_{it}} \right)^{1-\sigma} P_{it} Y_{it}$$

Trade share

$$\pi_{in,t} = \frac{\Omega_i^{\sigma-1} T_{it} \left(W_{nt} d_{in} (1 + \tau_{in,t}) \right)^{1-\sigma}}{\sum_{k=1}^{M} T_{kt} \left(W_{it} d_{ik} (1 + \tau_{ik}) \right)^{1-\sigma}}$$

Value innovation

$$V_{nt} = \sum_{i=1}^{M} J^{\text{innov}}_{in,t}$$

Profits firms

$$\Pi_{nt} = \frac{\sigma}{\sigma - 1} W_{nt} L_n$$

Value adopted technology

$$V^{\text{adopt}}_{in,t} = (1 - \chi_{in,t}) \frac{\Pi_{it}}{T_{it}} + \frac{1}{R_t} \frac{P_{it}}{P_{i,t+1}} V_{in,t+1}$$

Value un-adopted technology

$$J_{in,t}^{\text{adopt}} = -\frac{H_{in,t}^{a} P_{it}}{Z_{nt} - A_{in,t}} + \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}}[\varepsilon_{in,t} V_{in,t+1} + (1-\varepsilon_{in,t}) J_{in,t+1}]$$

Value adopted innovator

$$V_{in,t}^{\text{innov}} = \chi_{in,t}\frac{\Pi_{it}}{T_{it}} + \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}} V_{in,t+1}^{\text{innov}}$$

Value un-adopted innovator

$$J_{in,t}^{\text{innov}} = \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}}[\varepsilon_{in,t} V_{in,t+1}^{\text{innov}} + (1-\varepsilon_{in,t}) J_{in,t+1}^{\text{innov}}]$$

FOC innovation

$$H_{nt}^{r} = \beta_r \Delta Z_{nt}\frac{V_{nt}}{P_{nt}}$$

FOC adoption

$$P_{it} H_{in,t}^{a} = \beta_a \frac{1}{R_t}\frac{P_{it}}{P_{i,t+1}}(Z_{nt} - A_{in,t})\varepsilon_{in,t}(V_{in,t+1}^{\text{adopt}} - J_{in,t+1}^{\text{adopt}})$$

Probability of adoption

$$\varepsilon_{in,t} = \bar{\varepsilon}_{in}\left(\frac{H_{in,t}^{a}}{Y_{it}}\right)^{\beta_a}$$

Royalties

$$RP_{in,t} = \frac{A_{in,t}}{T_{it}}\Pi_{it}$$

Labor market-clearing condition

$$\bar{m} W_{nt} L_{nt} = \sum_{i=1}^{M}\frac{\pi_{in,t}}{1+\tau_{in,t}} P_{it} Y_{it}$$

Trade-balance equation

$$\sum_{i\neq n}^{M} T_{it} p_{ni,t} x_{ni,t} = \sum_{i\neq n}^{M} T_{nt} p_{in,t} x_{in,t} + \sum_{i=1}^{M} RP_{in,t} - \sum_{i=1}^{M} RP_{ni,t}$$

Law of motion of innovation

$$\Delta Z_{nt} = \lambda_n T_{nt} \left(\frac{H_{nt,r}}{Y_{nt}} \right)^{\beta_r}$$

Law of motion of adoption

$$\Delta A_{in,t} = \varepsilon_{in,t}(Z_{nt} - A_{in,t})$$

Interest rate

$$R_t = \frac{1}{\beta} \frac{C_{n,t+1}}{C_{nt}}$$

Total number of adopted technologies

$$T_{nt} = \sum_{i=1}^{M} A_{ni,t}$$

D Stationary Variables

Because this is an endogenous growth model and the endogenous variables grow along the BGP, I need to find the rate of growth of each variable and stationarize them appropriately. I also do some transformation of the variables. Here is a list of the equations written with stationarized variables that do not growth along the BGP.

From the equation of the home trade share, the growth of the real wage is $T^{\frac{1}{\sigma-1}}$. Also, as is common in these models of diffusion, all countries grow at a common rate. All adopted technologies and newly created technologies grow at the rate of Z.

Resource constraint:

$$\hat{Y}_{nt} = \hat{C}_{nt} + \hat{H}^r_{nt} + \hat{H}^a_{nt}$$

In this expression, $\hat{X}_{it} = \frac{X_{it}}{Z^{\sigma-1}_{Mt}}$. In this economy, the real wage grows at $Z^{\frac{1}{\sigma-1}}_{Mt}$. Real variables grow at $g_z/(\sigma - 1)$. Also note that in the Eaton and Kortum (2002) model, I get something similar, where $\theta = \sigma - 1$.

Prices:

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

where $\hat{\omega}_{nt} = \frac{W_{it}}{W_{Mt}}$ and $\hat{A}_{ni,t} = \frac{A_{ni,t}}{T_{Mt}}$.

Demand intermediate goods:

$$\hat{x}_{in,t} = \left(\bar{m}\hat{\omega}_{nt} d_{in}(1+\tau_{in,t})\right)^{1-\sigma} \hat{P}_{it}^{\sigma}\hat{Y}_{it} = \pi_{in,t}\hat{Y}_{it}\hat{P}_{it},$$

where $\hat{x}_{in,t} = \frac{\frac{p_{in,t}x_{in,t}}{W_{Mt}}}{Z_{Mt}^{\frac{1}{1-\sigma}}}$.

Trade share:

$$\pi_{in,t} = \frac{\Omega_n^{\sigma-1}\hat{T}_{nt}\left(\hat{\omega}_{nt} d_{in}(1+\tau_{in,t})\right)^{1-\sigma}}{\hat{P}_{it}^{1-\sigma}}$$

Value innovation:

$$\hat{v}_{nt} = \sum_{i=1}^{M} \hat{j}_{in,t}^{\text{innov}} \frac{\hat{T}_{nt}}{\hat{T}_{it}},$$

where $v_{nt} = T_{nt}V_{nt}/W_{Mt}$ and $j_{in,t}^{\text{innov}} = J_{in,t}T_{it}/W_{Mt}$.

Profits firms:

$$\hat{\Pi}_{nt} = \frac{1}{\sigma-1}\hat{\omega}_{nt}L_n$$

with $\hat{\Pi}_{it} = \frac{\Pi_t}{W_{Mt}}$.

Value adopted:

$$\hat{v}_{in,t} = (1-\chi_{in,t})\hat{\Pi}_{it} + \frac{1}{r_{it}}\frac{\hat{P}_{it}}{\hat{P}_{i,t+1}}\hat{v}_{in,t+1}\frac{(1+g_{Mt})^{1/\sigma-1}}{1+g_{T,it}}$$

with $\hat{V}_{in,t} = V_{in,t}T_{it}/W_{Mt}$.

Value unadopted:

$$\hat{j}_{in,t} = -\hat{H}_{in,t}^{a}\frac{\frac{\hat{T}_{it}}{\hat{A}_{in,t}}\varepsilon_{in,t}}{g_{in,t}^{a}} + \frac{1}{r_t}\frac{\hat{P}_{i,t+1}}{\hat{P}_{it}}\left[\varepsilon_{in,t}\hat{v}_{in,t+1} + (1-\varepsilon_{in,t})\hat{j}_{in,t+1}\right]\frac{(1+g_{M,t})^{1/\sigma-1}}{1+g_{T,it}},$$

where $r_t = R_t\frac{P_{nt}}{P_{n,t+1}}$ and $g_{T,it} = \hat{T}_{i,t+1}/\hat{T}_{it} - 1 + g_{Mt}$.

Value adopted innovator:

$$\hat{v}_{in,t}^{\text{innov}} = \chi_{in,t}\hat{\Pi}_{it} + \frac{1}{r_t}\frac{\hat{P}_{i,t+1}}{\hat{P}_{it}}\hat{v}_{in,t+1}^{\text{innov}}\frac{(1+g_{Mt})^{1/\sigma-1}}{1+g_{T,it}}$$

Value un-adopted innovator:

$$\hat{j}^{\text{innov}}_{in,t} = \frac{1}{r_t}\frac{\hat{P}_{i,t+1}}{\hat{P}_{it}}\left[\varepsilon_{in,t}\hat{v}^{\text{innov}}_{in,t+1} + (1-\varepsilon_{in,t})\hat{j}^{\text{innov}}_{in,t+1}\right]\frac{(1+g_{Mt})^{1/\sigma-1}}{1+g_{T,it}}$$

FOC innovation:

$$\beta_r\left(\frac{\hat{H}^r_{nt}}{\hat{Y}^w_t}\right)^{\beta_r-1}\hat{v}_{nt} = \hat{P}_{nt}\hat{Y}^w_t$$

FOC adoption:

$$\hat{P}_{it}\hat{H}^a_{in,t}\frac{\frac{\hat{T}_{it}}{\hat{A}_{in,t}}\varepsilon_{in,t}}{g^a_{in,t}} = \beta_a\frac{1}{r_t}\frac{\hat{P}_{i,t+1}}{\hat{P}_{it}}\varepsilon_{in,t}\left[\hat{v}_{in,t+1} - \hat{j}_{in,t+1}\right]\frac{(1+g_{Mt})^{1/\sigma-1}}{1+g_{T,it}}$$

Probability adoption:

$$\varepsilon_{in,t} = \bar{\varepsilon}_{in}\left(\frac{\hat{H}^a_{in,t}}{\hat{Y}_{it}}\right)^{\beta_a}$$

Royalties:

$$\hat{r}p_{in,t} = \frac{A_{in,t}}{T_{it}}\chi_{in,t}\hat{\Pi}_{it}$$

Labor market-clearing condition:

$$\bar{m}\hat{\omega}_n L_{nt} = \sum_{i=1}^{M}\pi_{in,t}\hat{Y}_{it}\hat{P}_{it}$$

Trade balance equation:

$$\sum_{i\neq n}^{M-1}\Omega_i^{\sigma-1}\hat{T}_{it}\hat{x}_{ni,t} = \sum_{i\neq n}^{M-1}\Omega_n^{\sigma-1}\hat{T}_{nt}\hat{x}_{in,t} + \sum_{i\neq n}^{M-1}\hat{r}p_{in,t} - \sum_{i\neq n}^{M-1}\hat{r}p_{ni,t} + \hat{B}_{it} - r_t\hat{B}_{i,t-1}$$

Law of motion of innovation:

$$g_{Z,nt}\hat{Z}_{nt} = \lambda_n\hat{T}_{nt}\left(\frac{\hat{H}_{nt,r}}{\hat{Y}_{nt}}\right)^{\beta_r}$$

Law of motion of adoption:

$$g^a_{in,t} = \varepsilon_{in,t} \left(\frac{\hat{Z}_{nt}}{\hat{A}_{in,t}} - 1 \right),$$

where $g^a_{in,t} = (\hat{A}_{in,t+1} - \hat{A}_{in,t}) + g$

Bond holdings

$$1 + \eta \left(\hat{B}_{nt} - \bar{B}_n \right) = r_t \beta (1 + g_{c,n,t+1})$$

with $1 + g_{c,t+1} = \hat{C}_{n,t+1}/\hat{C}_{nt} - 1 + (1+g)^{\sigma-1}$. A small quadratic-adjustment cost in bond holding, η, guarantees the existence of a unique BGP value for $B_n = \bar{B}_n$.

Bond-market equilibrium:

$$\sum_{n=1}^{M} \hat{B}_{nt} = 0$$

Total number of adopted technologies

$$\hat{T}_{nt} = \sum_{i=1}^{M} \hat{A}_{ni,t}$$

E BGP

The parameters of the model are $\{\beta, \eta, \beta_a, \beta_r, \sigma, \lambda_n, \bar{\varepsilon}_{in}, \xi_{in,t}, \chi_{in,t}, d_{in}, \tau_{in,t}, g\}$.

To solve for the BGP, I can use the expressions from the previous section, which are stationary and do not grow along the BGP. I drop the time dimension and the hats.

Note that from the law of motion of adopted varieties,

$$A_{in} = \frac{\varepsilon_{in}}{g + \varepsilon_{in}} Z_n.$$

I will start by guessing a vector for T_n, a value for g, a matrix for $H^a in$, and a vector for wages, and then solve for the equilibrium for wages, prices, trade shares, and income. Wages will be updated using the trade-balance equation, and inside that loop there will be a recursive algorithm to solve for the equilibrium value of $H^a in$. I can then use the Perron-Frobenius theorem to solve for g and T_n/T_M.

To solve for the equilibrium along the BGP, I need the following expressions:

1. Start by guessing w_n, H_{in}^a, g, and T_n

2.
$$r = \frac{1 + g/(\sigma - 1)}{\beta}$$

3.
$$P_n^{1-\sigma} = \sum_{i=1}^{M} \Omega_i^{\sigma-1} T_i \left(\bar{m}\omega_i d_{ni}(1 + \tau_{ni,t})\right)^{1-\sigma}$$

4.
$$\pi_{in} = \frac{T_n \left(\bar{m}\omega_n d_{in}(1 + \tau_{in,t})\right)^{1-\sigma}}{P_i^{1-\sigma}}$$

5.
$$\omega_n L_n = \sum_{i=1}^{M} T_n \left(\frac{\bar{m}\omega_n d_{in}(1 + \tau_{in,t})}{P_i}\right)^{1-\sigma} \frac{Y_i P_i}{1 + \tau_{in,t}}$$

   This can be written as

$$\omega_n L_n = \sum_{i=1}^{M} \frac{\pi_{in}}{1 + \tau_{in,t}} Y_i P_i,$$

   which can be written in matrix form as $\omega L = BY$ with each entry of B being $b_{in} = \frac{\pi_{in}}{1+\tau_{in,t}}$.

6. An update rule for wages: Note that because there are royalties, I will not be able to update wages at this stage without first knowing A_{in}, which enters the equation for royalties. To do that I need to guess for H_{in}^a, which I already did, and then use the growth block of the model to update H_{in}^a:

$$\sum_{i \neq n}^{M} \frac{\pi_{ni}}{1 + \tau_{ni,t}} Y_n = \sum_{i \neq n}^{M} \frac{\pi_{in}}{1 + \tau_{in,t}} Y_i + \sum_{i \neq n}^{M} r p_{in} - \sum_{i \neq n}^{M} r p_{ni},$$

   where

$$\sum_{n \neq i} \frac{RP_{in} T_i}{W_M} = \sum_{n \neq i} \frac{\Delta A_{in}}{A_{in}} \frac{V_{in} T_i}{W_M} \frac{A_{in}}{T_i}$$

$$\sum_{n \neq i} r p_{in} = \sum_{n \neq i} g V_{in} \frac{A_{in}}{T_i}$$

7.

$$v_{in} = \left(1 - \frac{1}{r} \frac{1 + g/(1/\sigma - 1)}{1 + g}\right)^{-1} \Pi_i$$

8. I combine the law of motion for A_{in} with the definition of ε_{in} to obtain

$$\varepsilon_{in} = \bar{\varepsilon}_{in} \left(\frac{H_{in}^a}{Y^w}\right)^{\beta_a}.$$

Note that the law of motion for new varieties tells us that

$$\frac{A_{in}}{Z_n} = \frac{\varepsilon_{in}}{\varepsilon_{in} + g}.$$

9. I combine the expression for the FOC of adoption together with the expression for the value of an unadopted technology to obtain an expression for j_{in}:

$$j_{in} = \left(1 - \beta_a \varepsilon_{in} \frac{1}{r} \frac{1 + g/(1/\sigma - 1)}{1 + g} - \frac{1}{r} \frac{1 + g/(1/\sigma - 1)}{1 + g} (1 - \varepsilon_{in})\right)^{-1} (1 - \beta_a) \varepsilon_{in} \frac{1}{r} \frac{1 + g/(1/\sigma - 1)}{1 + g} v_{in}$$

10.

$$V_n = \sum_{i=1}^{M} J_{in} \frac{T_n}{T_i}$$

11.

$$H_n^r = \left(\beta_r V_n \lambda_n Y_n^{-\beta_r}\right)^{1/(1-\beta_r)}$$

12. I use the FOC of adoption to update for adoption, but for that I need an expression for $\frac{A_{in}}{T_i}$. I use the following expressions:

$$A_{in} = \frac{\varepsilon_{in}}{g + \varepsilon_{in}} (1 + g) Z_n$$

$$Z_n = \frac{\lambda_n}{g} T_n \left(\frac{H_n^r}{Y_n}\right)^{beta_r}$$

$$T_i = \sum_{i=1}^{M} A_{in}$$

13. I plug into the FOC for adoption and update H_{in}^a.

14. I use the trade balance equation to update wages. If there are M countries, I need $M-1$ updating equations because one of the equations is redundant.

15. Update g and T_n with the Perron-Frobenius theorem and equation

$$T_i g = \sum_{n=1}^{M} \frac{\varepsilon_{in}}{\varepsilon_{in}+g} \lambda_n \left(\frac{H_n^r}{Y_n}\right)^{\beta_r} T_n.$$

In matrix form, that expression becomes

$$gT = \Delta(g)T,$$

where $\Delta(g)$ is a $M * M$ matrix with entry $\Delta_{in} = \frac{\varepsilon_{in}}{\varepsilon_{in}+g}\lambda_n \left(\frac{H_n^r}{Y_n}\right)^{\beta_r}$

From the Perron-Frobenius theorem, as long as matrix Δ is idecomposable, it exists a unique g, which is given by the maximum real eigenvalue of the matrix, and the eigenvector associated with that eigenvalue gives T, which is unique up to a scalar. So I can just compute $\hat{T}_i = T_i/T_M$.