

Dynamic Gains from Trade Agreements with Intellectual Property Provisions*

Ana Maria Santacreu[†]

September 5, 2022

Abstract

I develop a quantitative multi-country trade model of innovation and technology licensing to study short- and long-term effects of trade agreements with intellectual property (IP) provisions. A trade agreement involves determining the level of tariffs and IP protection as Nash bargaining between a developed and a developing country. The agreement increases welfare, innovation, and growth in the long run. However, gains accrue differently across countries along the transition. Developing countries experience short-run losses, as they now pay higher licensing prices. An agreement designed by a politically-motivated government could mitigate these losses, but at the expense of lower growth and welfare.

Keywords: Technology Licensing; Trade Agreements; Intellectual Property Rights

JEL Classification: F12, O33, O41, O47

*This version supersedes an older version titled “Intellectual Property Rights, Technology Transfer and International Trade.”

[†]Santacreu, Federal Reserve Bank of St. Louis, email: am.santacreu@gmail.com. I am grateful to Chris Tonetti for his very insightful comments and suggestions during his discussion. I thank George Alessandria, Chad Bown, Jonathan Eaton, Gianmarion Impullitti, Sam Kortum, Jesse LaBelle, Fernando Leibovici, Omar Licandro, Fernando Parro, and Esteban Rossi-Hansberg for very insightful comments, and Jesse LaBelle for excellent research assistance. I also thank participants at the U. of Melbourne, Saint Louis Macro-Trade Workshop, Vanderbilt University, Penn State University, the University of Nottingham, Claremont McKenna College, the North American Econometric Society Winter Meetings 2022, the 2021 Ron Jones International Trade and Macroeconomics Workshop at the U of Rochester, the University of Tokyo, the Federal Reserve Bank of Saint Louis, the Virtual Trade and Macroeconomics Workshop, Goettingen University, and Universitat Autònoma de Barcelona. The views in this paper are those of the author and do not necessarily reflect the views of the Federal Reserve Bank of St. Louis or the Federal Reserve System.

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 and required only minimum standards of IP enforcement. However, recent decades have seen substantial improvements in IPR with most agreements since 1995 containing such provisions.¹ RTAs with IP provisions require that countries signing the agreement reach IP standards similar to those in developed countries. In return, they offer increased access to international markets. These are known as deep trade agreements. 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 IP laws.² More recently, in August 2007 the United States, under Section 301 of the US Trade Act, initiated 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 U.S. imports from China.³

This paper studies, through the lens of a quantitative dynamic trade model, the short- and long-run implications of negotiating trade agreements with IP provisions on innovation, growth, and welfare. Recent papers have studied welfare effects of trade negotiations on tariffs (see Bagwell, Staiger, and Yurukoglu, 2021, 2020; Ossa, 2011, 2014). However, the literature modeling negotiations of non-tariff issues such as IP is still limited.⁴ IPR reforms impact *dynamic* gains from trade through changes in the incentives to innovate. Welfare gains from trade have been typically evaluated with static models (Arkolakis, Costinot, and Rodríguez-Clare, 2012), which are not able to capture short- and medium-term effects of changes in trade policy. A growing literature has emerged studying dynamic welfare gains in models of trade and innovation. While most of this work has focused on the balanced growth

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

²In 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>.

⁴Maggi 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 into deep integration.

path (BGP)—see Cai, Li, and Santacreu (2021); Somale (2021); Sampson (2019); Lind and Ramondo (2022)—very few papers compute welfare gains along the transition (Akcigit, Ates, and Impullitti, 2018; Perla, Tonetti, and Waugh, 2015; Buera and Oberfield, 2019). Finally, although there is 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), the connections with trade in the context of deep trade agreements have not been explored quantitatively.⁵ This paper contributes to the literature by exploring both theoretically and quantitatively the short- and long-term dynamic gains of reforming IPR as part of a trade agreement that includes non-tariff issues.

I develop a quantitative Armington trade model of **endogenous productivity** through both **innovation and technology licensing**. **Innovators** invest resources to create a new technology; **adopters** invest resources to use the technology, either domestic or foreign, in the production of an intermediate good. Adoption is a slow and costly process: With a certain probability, which depends on adoption intensity, adopters can use the technology to produce an intermediate good with monopolistic competition. In this case, adopters earn profits from intermediate producers and pay royalties to innovators. Royalties are paid, each period, as a share of total profits made by the adopters in that period. The model allows for **imperfect enforcement of IPR** since adopters may not pay the royalty fee in full. The level of IP enforcement varies from perfect enforcement (royalty payments are paid as agreed) to pure imitation (no royalty payments). I assume that countries cannot export the goods produced with imitated technology. The model has a BGP in which all countries grow at the same rate but differ in relative levels. Differences in growth rates across countries arise along the transition.

The model is calibrated to 2000 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, the quality of IP protection, and their geography and trade policy. A novelty of the calibration strategy in this paper is that it estimates the probability of adoption using data on international technology licensing. The model yields a structural gravity equation of bilateral royalty payments that can be estimated with gravity methods to compute the probability of adoption

⁵Some exceptions include Holmes, McGrattan, and Prescott (2015) and Mandelman and Waddle (2019).

across country-pairs on the BGP. Santacreu (2021) shows, using data on bilateral royalty payments for 41 countries and the period 1995-2012, that international technology licensing around the world has substantially increased during the period of analysis, becoming an important source of technology transfer. Moreover, royalty payments are a more direct form of technology diffusion than other measures used in the literature such as international patenting, trade, or patent citations (see Eaton and Kortum, 1996, 1999; Santacreu, 2015; Buera and Oberfield, 2019; Cai, Li, and Santacreu, 2021).

I conduct a counterfactual exercise in which China and the United States negotiate a trade agreement consisting of choosing the levels of tariffs and IP protection as part of a Nash bargaining problem. Although China and the United States do not currently have a trade agreement with IP provisions, the United States has mechanisms in place to restrict imports from developing countries with poor IP protection (section 337 of the US Tariff Act, Section 301 and special 301 or Generalized system of preferences). Moreover, 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 from Chinese goods in exchange for China, among other things, improving its IP protection. The agreement in this paper is designed similarly to Bagwell, Staiger, and Yurukoglu (2020, 2021), who solve for optimal tariffs resulting from various bilateral trade agreements. The main difference is that I consider a trade agreement between one country pair on both tariffs and non-tariff instruments. The payoff function is the pair's Nash bargaining product of dynamic welfare gains, computed as consumption-equivalent units, and the strategies are the tariffs and quality of IP protection, both domestic and foreign, being negotiated between the pair. The trade agreement is conditional on both countries having positive welfare gains. The optimal agreement implies: (i) Reforms of Chinese IP laws so domestic and foreign firms receive higher royalty payments; and (ii) lower US tariffs on imported Chinese products.⁶

I solve for the perfect foresight solution of the model after the agreement is signed, which is an unanticipated, permanent, one-time shock. The trade agreement increases innovation and growth in the long run everywhere. Innovators, both in China and in the United States, receive more royalties, which increases their returns to R&D. Adoption increases in the United States, as there are more technologies ready to be used in production. Adopters

⁶Several trade agreements with IP provisions require strengthening and harmonizing IP laws among countries by requiring uniform minimum standards of IP protection and enforcement in domestic laws—an example includes the Trans-Pacific Partnership Agreement.

in China are impacted by two opposing forces: The return to adoption decreases, as they now have to pay more royalties; however, they have access to a larger market through lower tariffs, which increases adoption incentives. The net effect is a decline in adoption. Hence, resources reallocate away from adoption and toward innovation in China. Welfare increases in all countries as higher innovation around the world drives the BGP growth rate up. However, there are heterogeneous cross-country effects on how gains accrue along the transition. Despite benefiting from lower tariffs, China suffers short-term losses, as adopters must now pay for technology that was previously copied; short-term gains occur in the United States, as innovators receive more royalties and the return on innovation increases.

I perform several counterfactual exercises to disentangle the main channels at play. First, IP protection is reformed without trade liberalization. In this case, all countries experience positive gains. However, China experiences a larger initial drop in consumption, as the standard forces of a trade liberalization are not present. Overall, China gains but less than when the United States lowers tariffs on imported products. In a second counterfactual exercise, the United States lowers tariffs on Chinese exports but China maintains imperfect IP protection. In this case, China experiences short-term gains, while the US suffers losses. Moreover, there are dynamic losses everywhere through lower R&D investment and lower long-term growth. On the one hand, US innovators are not compensated from their R&D efforts, decreasing innovation and long-term growth. On the other hand, US firms face higher competition from imitated Chinese products through lower tariffs. This effect reinforces the decrease in innovation and long-term growth, leading to long-term welfare losses.

An important component of the trade agreement is that China has to reform its domestic IP laws. This feature is motivated by current trade agreements that require significant changes in the domestic legislation of participating countries.⁷ Improving domestic IPR implies that domestic innovators receive more royalties, thus invest more in R&D. At the same time, China benefits from lower tariffs from the United States, but China has to pay higher prices for using foreign technology. The question, then, is whether China would be better off by reforming its domestic IP laws without signing a trade agreement, or whether there are additional benefits from doing such reforms as part of an agreement. I find that improving domestic IPR unilaterally generates positive welfare gains both in the short- and in the long-run in China. However, the gains are lower if IP laws are not reformed as part

⁷See https://unctad.org/system/files/official-document/iteipc20064_en.pdf.

of a trade agreement. That is, the positive effects of domestic IP reforms and having access to a larger export market dominate the negative effects of paying higher prices for licensed technology. Therefore, signing the trade agreement not only encourages China to improve its IPR, but it also offers access to larger export markets through lower tariffs, thereby compensating for the higher adoption prices as royalties.

Finally, the main trade agreement has been designed by a welfare-maximizing government. That is, tariffs and levels of IP protection are selected so as to maximize welfare as calculated in consumption-equivalent units at the consumer's discount factor. China suffers short-term losses in this case, but both countries gain overall. These losses in China might not be attractive to a politically motivated government with short-term goals.⁸ I then consider the design of a trade agreement made by a government with short-term objectives (i.e., the government is more impatient and has a lower discount factor). Here, the trade agreement generates positive gains, both in the short-run and in the long-run, everywhere, but the overall gains are lower than in the welfare-maximizing trade agreement. The reason is that when an agreement is designed by a politically-motivated government, China agrees to improve foreign IP less than before, resulting in a lower increase of the BGP growth rate.

One of the model's implications of trade agreements with strict IP provision is that royalty payments from China to the United States increase following the agreement. The increase occurs for two reasons: (i) China starts paying royalties for technology it was previously getting for free, and (ii) China starts receiving more foreign technology, hence paying royalties for it. In contrast, trade agreements that do not require IP improvements have no effect on royalty payments. I provide empirical validation for this channel by studying the dynamics of international technology transfer in the data following membership into RTAs with IP provisions. I find that country-pairs that sign RTAs with strict IP provisions experience more royalty payments following the year of enforcement. These results are stronger when the agreement is signed between developed and developing countries. An econometric analysis that includes country-time fixed effects and country-pair fixed effects shows that only RTAs with IP provisions matter for royalty payments between developed and developing countries, increasing these payments by 25% following an agreement. The model can thus capture the dynamics of technology licensing observed in the data, following the enforcement of a trade agreement with strict IP provisions. This result provides empirical support for the main

⁸See Grossman and Helpman (1995) and Grossman (2016).

channel of technology transfer in the model.

The remaining of the paper is organized as follows. Section 2 presents the model. Section 3 describes the calibration and counterfactual analysis. Section 4 presents external validation and Section 5 concludes.

2 Model

The world consists of M countries indexed by i and n . Time is discrete and indexed by t . Productivity in each country evolves endogenously through innovation and technology adoption.

2.1 Preferences

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

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

subject to the budget constraint

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

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_{nr} (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.

2.2 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:

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

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 ; and $\sigma > 1$ is the elasticity of substitution across intermediate products.

The demand for intermediate goods is given by

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

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:

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

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:

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

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, τ_{in} ,

whereby $1 + \tau_{in}$ is the gross tax rate that country i levies on the value of imports from country n . 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 is given by

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

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 trade costs 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 (*adoption*). I explain these processes in detail next.

2.3 Innovation and Technology Adoption

The number of technologies available to produce intermediate goods, T_{nt} , evolves endogenously through innovation and technology adoption.

Innovation In each country n a monopolist invests final output, H_{nt}^r , to produce a new prototype or technology. Technologies arrive at a Poisson process given by

$$\lambda_n T_{nt} \left(\frac{H_{nt}^r}{\bar{Y}_t} \right)^{\beta_r}, \quad (8)$$

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 learn from domestic and foreign technology that is being used to produce intermediate goods. Moreover, \bar{Y}_t is

world output and β_r is diminishing returns to adding one extra unit of final output into the innovation process.

The stock of technology innovated in each period is given by the following law of motion:

$$Z_{n,t+1} = \lambda_n T_{nt} \left(\frac{H_{nt}^r}{\bar{Y}_t} \right)^{\beta_r} + Z_{n,t}. \quad (9)$$

Equation (9) implies that there is no depreciation of new ideas over time.

New technologies developed through innovation need to be adopted to be used in the production of a new intermediate product. This process is called adoption. Innovators have a monopoly over the technology, which they license to adopters. The value of an innovation is given by V_{nt} , and it will be defined later.

The innovator chooses H_{nt}^r to maximize

$$\Delta Z_{nt} V_{nt} - P_{nt} H_{nt}^r. \quad (10)$$

Technology Adoption When a new prototype is introduced in country n , the innovator in that country licenses the technology to an adopter that invests resources to make it usable for production of intermediate goods. 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 $h_{in,t}^a$ 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

$$\varepsilon_{in,t}(j) = \bar{\varepsilon}_{in} \left(\frac{h_{in,t}^a(j)}{\bar{Y}_t} \right)^{\beta_a}, \quad (11)$$

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:

$$A_{in,t+1} = \varepsilon_{in,t} (Z_{nt} - A_{in,t}) + A_{in,t}. \quad (12)$$

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 good and pay a royalty fee to the innovator. I assume that royalties are paid as a fraction of the profits made by the adopter once the technology has been adopted.

2.4 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 share $\chi_{in,t}$ of profits made by intermediate producers in country i that use the technology from country n ; that is,

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

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. I assume that the royalty fee has two components; that is, $\chi_{in,t} = \bar{\chi}_{in,t} \xi_{in,t}$, where $\bar{\chi}_{in,t}$ represents a royalty fee implicitly negotiated by the innovator in country n and the adopter in country i , and $\xi_{in,t}$ is the quality of IP protection, ranging from 0 if there is pure imitation to 1 if there is perfect enforcement of IPR.⁹

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

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

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 but can keep trying to adopt the technology in the future. 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 share of intermediate producers' profits that operate with the innovator's tech-

⁹I take the royalty fee $\bar{\chi}_{in}$ as given. An alternative would be to model the negotiation process between the innovator and the adopter, which would take the form of Nash bargaining. See Benhabib, Perla, and Tonetti (Forthcoming) and Hopenhayn and Shi (2020) for examples of models of licensing where the royalty fee is negotiated in advance.

nology once the technology has been adopted. 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

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

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

$$V_{in,t}(j) = (1 - \chi_{in,t})\pi_{it}^n(j) + \frac{1}{R_{it}}V_{in,t+1}(j). \quad (13)$$

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

$$J_{in,t}(j) = -P_{it}h_{in,t}^a(j) + \frac{1}{R_{it}}\{\varepsilon_{in,t}V_{in,t+1}(j) + (1 - \varepsilon_{in,t})J_{in,t+1}(j)\}. \quad (14)$$

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 $t + 1$.

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

In equilibrium, $h_{in,t}(j) = h_{in,t} \forall j$. Hence, $\varepsilon_{in,t}(j) = \varepsilon_{in,t}$, with

$$\varepsilon_{in,t} = \bar{\varepsilon}_{in} \left(\frac{H_{in,t}^a}{Y_{it}} \right)^{\beta_a}. \quad (15)$$

The FOC of adoption is

$$P_{it}H_{in,t}^a = \varepsilon_{in,t} \frac{1}{R_{it}}(V_{in,t+1} - J_{in,t+1}).$$

2.5 Market-Clearing Conditions

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

$$P_{nt}Y_{nt} = P_{nt}C_{nt} + P_{nt}H_{nt}^r + P_{nt} \sum_{i=1}^M H_{ni,t}^a. \quad (16)$$

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

$$W_{nt}L_{nt} = \sum_{i=1}^M T_{nt}W_{nt}l_{in,t} = \sum_{i=1}^M T_{nt} \frac{p_{in,t}}{\bar{m}d_{in}(1 + \tau_{in})} x_{in,t}d_{in}. \quad (17)$$

From here,

$$\bar{m}W_{nt}L_{nt} = \sum_{i=1}^M T_{nt} \frac{p_{in,t}x_{in,t}}{1 + \tau_{in}} = \sum_{i=1}^M \frac{\pi_{in,t}}{1 + \tau_{in}} P_{nt}Y_{nt}. \quad (18)$$

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

$$\text{IBT}_{nt} = \sum_{i \neq n}^{M-1} \frac{\tau_{ni}}{1 + \tau_{ni}} \pi_{ni,t} P_{nt}Y_{nt}. \quad (19)$$

From the budget constraint of consumers, I derive an expression for the balance of payments. Note that royalties are a trade service, so they will appear as part of net exports. Also note that there is borrowing and lending with the rest of the world, so there are trade imbalances:

$$\sum_{i \neq n}^{M-1} \frac{T_{it}p_{ni,t}x_{ni,t}}{1 + \tau_{ni}} = \sum_{i \neq n}^{M-1} \frac{T_{nt}p_{in,t}x_{in,t}}{1 + \tau_{in}} + \sum_{i \neq n}^{M-1} RP_{in,t} - \sum_{i \neq n}^{M-1} RP_{ni,t} + R_t B_{n,t-1} - B_{nt}, \quad (20)$$

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

The world market-clearing condition for bonds is given by

$$\sum_{n=1}^M B_{nt} = 0. \quad (21)$$

Finally, there is a government that collects import tariffs and rebates them back to consumers lump sum:

$$\text{IBT}_{nt} = \sum_{i=1}^M \frac{\pi_{ni,t}}{1 + \tau_{ni,t}} Y_{nt} \tau_{ni,t}. \quad (22)$$

2.6 Balanced Growth Path

Cross-country adoption guarantees that the model has a unique BGP equilibrium in which all countries grow at a constant rate but differ in relative levels. Growth on the BGP is endogenous. Changes in trade costs, d_{in} , and in the quality of IPR enforcement, χ_{in} , have both growth and level effects. I stationarize all the endogenous variables so that they are constant on the BGP, denote the normalized variables with a hat, and remove all time subscripts in the derivation. Here I characterize the BGP growth rate of the economy.

The stock of knowledge T_n grows at the constant rate g , which is common across all countries. Combining equations (9) and (12), I can express the BGP growth and relative productivity of country i as

$$gT_i = \sum_{n=1}^M \frac{\varepsilon_{in}}{\varepsilon_{in} + g} \lambda_n T_n \left(\frac{H_n^r}{Y_n} \right)^{\beta_r}. \quad (23)$$

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

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

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 trade costs, d_{in} , and IPR, χ_{in} , have an effect on g and T through changes in H_n^r/Y_n and ε_{in} .

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.

3 Quantitative Analysis

The model is calibrated to data on trade flows, geography, income, R&D spending, and international technology licensing for the year 2000 for 41 countries aggregated into three regions: the United States, China, and an aggregate rest of the world. A quantitative exercise evaluates the effects on innovation, growth, and welfare of a trade agreement by which China improves its IPR and benefits from lower tariffs when exporting to the United States. I then evaluate the short-term and long-term effects of the agreement, assuming that it is perfectly enforced.¹⁰ To explore further the interaction between trade liberalization and IP reforms, I evaluate the model under three alternative counterfactual scenarios: (i) China reforms its IP but the United States does not lower its tariffs on Chinese imports; (ii) the United States lowers its tariffs but China does not reform its IP; and (iii) China improves its domestic IP laws but does not sign a trade agreement.

3.1 Calibration

Some of the parameters of the model are calibrated using values from the literature; others are estimated outside the model by running gravity regressions; the remaining parameters are calibrated by solving the BGP of the model, taking as given the value of the other parameters. I begin by describing the parameters that are calibrated 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 0.96, which implies an annual interest rate of 4%. The remaining parameters of the model are calibrated in three steps using data on trade flows, geography, R&D spending, income, and royalty payments for the year 2000. First, I calibrate trade costs and productivity, estimating a gravity equation of bilateral trade flows, following Waugh (2010). Second, I calibrate the adoption parameters estimating a BGP gravity equation of bilateral royalty payments, following the methodology developed in Santacreu (2021). Third, I calibrate the innovation parameters, adapting the algorithm developed by Cai, Li, and Santacreu (2021). I provide details on the calibration strategy next. The calibrated parameters are reported in Table 1.

¹⁰I 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: It involves more royalty payments and lower tariffs.

Trade costs and relative productivity Using data on bilateral trade flows, geography, and GDP per capita from CEPII for 2000, I calibrate transport costs, $d_{in}(1 + \tau_{in})$, and productivity, $\Omega_n^{\sigma-1}T_n$, by running the following reduced-form regression, derived from manipulating equation (33):

$$\left(\frac{X_{in}}{X_{ii}}\right) = \exp \left(-(\sigma - 1) \sum_{p=1}^6 d_{in,p} - (\sigma - 1)B_{in} + \log(S_n) - \log(S_i) + u_{in} - (\sigma - 1)fe_n + u_{in} \right),$$

where, following Eaton and Kortum (2002), $d_{in,p}$ is the contribution to trade costs of the distance between country n and i falling into the p^{th} interval (in miles), defined as $[0, 350]$, $[350, 750]$, $[750, 1500]$, $[1500, 3000]$, $[3000, 6000]$, $[6000, \text{maximum}]$. The other control variables are in B_{ni} and include a common border effect, common currency effect, and regional trade agreement between country n and country i . I include an exporter fixed effect, S_n ; an importer fixed effect, $\log(S_i)$; and an exporter fixed effect, $\log(S_n) - (\sigma - 1)fe_n$, where fe_n is part of the trade costs, which has been shown to better fit the patterns both in country incomes and in observed price levels (see Waugh, 2010). According to the model, $S_i = \Omega_i^{\sigma-1}T_i \left(\frac{\omega_i}{P_i}\right)^{1-\sigma}$. Using the estimated value for S_i , data on GDP per capita, and $\sigma = 5$, I recover $\Omega_i^{\sigma-1}T_i$ and obtain trade costs from the following expression:

$$-(\sigma - 1) \log(d_{in}(1 + \tau_{in})) = -(\sigma - 1) \sum_{p=1}^6 d_{in,p} - (\sigma - 1)B_{in} - (\sigma - 1)fe_n.$$

Finally, I use data on bilateral tariffs from UN-CTAD to calibrate τ_{in} and back out the iceberg transport costs, d_{in} , from the gravity estimation results. The results are reported in the top panel of Table 1.

Probability of Adoption A novelty of the calibration strategy in this paper is that it estimates the probability of adoption using data on bilateral royalty payments and gravity methods. The model yields a structural gravity equation of royalty payments that can be estimated and allows us to infer the probability of adoption across country-pairs. Royalty payments are a more direct form of technology diffusion than other measures used in the literature such as international patenting, trade, or patent citations. See Santacreu (2021) for a detailed description of the advantages and drawbacks of using royalty payments as a

measure of trade in intangibles.

In particular, I calibrate the probability of adoption, ε_{in} , by estimating a structural gravity equation of royalty payments from the BGP of 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 (12) and (9) on the BGP, I obtain an expression for royalty payments given by

$$RP_{in,t} = \frac{\varepsilon_{in}}{\varepsilon_{in} + g} \lambda_n T_{nt} \left(\frac{H_{nt}^r}{Y_t^w} \right)^{\beta_r} \Pi_{it}. \quad (24)$$

Note that this expression resembles a gravity equation with exporter-time and importer-time fixed effects and time-invariant bilateral fixed effects. Taking logs of 24,

$$\log(RP_{in,t}) = fe_{in} + S_{nt} + F_{it} \quad (25)$$

with $fe_{in} = \log\left(\frac{\varepsilon_{in}}{\varepsilon_{in} + g}\right)$, $S_n = \log\left(\lambda_n \frac{T_n}{T_i} \left(\frac{H_n^r}{Y_n}\right)^{\beta_r}\right)$, and $F_i = \log\left(\frac{\Pi_i}{T_i}\right)$. I then estimate the nonlinear version of equation (25) with PPML methods as in (Santacreu, 2021). In particular, I regress bilateral royalty payments on exporter-time, importer-time, and country-pair fixed effects. I recover ε_{in} from the bilateral fixed effects, assuming a productivity growth rate of 1.85%. Finally, I impose instantaneous adoption within the country so that $\varepsilon_{ii} = 1$. In that way, ε_{in} reflects the probability of adoption relative to the importer's domestic probability of adoption. The results are reported in Table 1.

The royalty fee structure I calibrate the royalty fee structure by setting a value for $\bar{\chi}_{in}$ and the quality of IPR ξ_{in} as follows. First, I assume that innovators charge a royalty fee of 25% to both domestic and foreign adopters. This assumption follows the 25% rule by which a party selling a product based on another party's IP must pay that party a royalty of 25% of the gross sales profit before taxes.¹¹ 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, since adopters incur costs to learn how

¹¹<https://assets.kpmg/content/dam/kpmg/pdf/2015/09/gvi-profitability.pdf>.

to use the technology, they may need a lower royalty fee to have incentives to invest in adoption.¹²

Finally, I assume that there is perfect enforcement of IPR in the United States and in the rest of the world but partial enforcement in China. That is, $\xi_{in} = 1, \forall n$ and $i = \{\text{US, ROW}\}$. However, Chinese adopters only pay a fraction of the agreed royalty fee either domestically or abroad, so that $\xi_{in} = 0.01, \forall n$ and $i = \{\text{CHN}\}$.

Parameters calibrated within the model The remaining parameters, which are calibrated by solving the model on the BGP, are $\beta_r, \beta_a, \lambda_n, \Omega_n$, and $\bar{\varepsilon}_{in}$. I calibrate β_r and λ_n to match a productivity BGP growth rate of 1.85% and R&D intensity data for 2000. In particular, I adapt the algorithm developed by Cai, Li, and Santacreu (2021), which uses the expression for the BGP growth rate in equation (23) and the Frobenius theorem. This algorithm delivers productivity T_n also, which then allows me to back out Ω_n from the estimated $\Omega_n^{\sigma-1}T_n$. Finally, I set $\beta_a = \beta_r$, since there are no bilateral data on adoption spending, and recover $\bar{\varepsilon}_{in}$ by setting ε_{in} to its calibrated value when solving the model.

3.2 Counterfactual Analysis: Trade Agreement with IP Provisions

I conduct a counterfactual analysis that consists of the United States and China signing a trade agreement with IP provisions. In this agreement, China improves its IPR both domestically and abroad and then benefits from lower tariffs when exporting to the United States. The trade agreement is designed as the solution of a Nash bargaining problem between the two countries, along the lines of Bagwell, Staiger, and Yurukoglu (2020) and Bagwell, Staiger, and Yurukoglu (2021). The payoff function is the pair's Nash bargaining product, and the strategies are the tariffs and quality of IPR enforcement being negotiated by the pair. I then evaluate the effect of this trade agreement on innovation, growth, and welfare. I solve for the perfect foresight solution of the model following the unanticipated, permanent, one-time shock that is the trade agreement.¹³

¹²Alternatively, 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 (Forthcoming) and Hopenhayn and Shi (2020).

¹³The 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).

Table 1: Calibrated parameters

Parameter	Value	Source
$\Omega_{\text{US}} (T_{\text{US}})^{1/\sigma-1}$	6.25	Gravity trade
$\Omega_{\text{ROW}} (T_{\text{ROW}})^{1/\sigma-1}$	2.41	Gravity trade
$\Omega_{\text{China}} (T_{\text{China}})^{1/\sigma-1}$	1.00	Gravity trade
$d_{\text{USA,ROW}}(1 + \tau_{\text{USA,ROW}})$	2.73	Gravity trade
$d_{\text{USA,China}}(1 + \tau_{\text{USA,China}})$	2.95	Gravity trade
$d_{\text{ROW,USA}}(1 + \tau_{\text{ROW,USA}})$	6.23	Gravity trade
$d_{\text{ROW,China}}(1 + \tau_{\text{ROW,China}})$	6.20	Gravity trade
$d_{\text{China,USA}}(1 + \tau_{\text{China,USA}})$	3.18	Gravity trade
$d_{\text{China,ROW}}(1 + \tau_{\text{China,ROW}})$	2.90	Gravity trade
$L_{\text{US}}/L_{\text{China}}$	0.23	CEPII
$L_{\text{ROW}}/L_{\text{China}}$	1.33	CEPII
$\varepsilon_{\text{USA,ROW}}$	0.36	Gravity royalties
$\varepsilon_{\text{USA,China}}$	0.24	Gravity royalties
$\varepsilon_{\text{ROW,USA}}$	0.31	Gravity royalties
$\varepsilon_{\text{ROW,China}}$	0.14	Gravity royalties
$\varepsilon_{\text{China,USA}}$	0.27	Gravity royalties
$\varepsilon_{\text{China,ROW}}$	0.24	Gravity royalties
β_r	0.47	Match $g = 1.85\%$
β_a	0.47	Set $\beta_a = \beta_r$
λ_{US}	0.33	Match R&D intensity in USA
λ_{ROW}	0.28	Match R&D intensity in ROW
λ_{China}	0.19	Match R&D intensity in China
$\bar{\chi}_{in}$	0.25	Royalty fee
ξ_{in}	1.00	Perfect enforcement IPR $i = \{\text{US, ROW}\}$
$\xi_{\text{China},n}$	$\chi_{\text{China},n} = 0.01$	Partial enforcement of IPR

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, $\xi_{\text{China},n} = \xi_{\text{China}} \forall n$. The details of the trade agreement are determined as the solution of the following Nash bargaining problem:

$$\max_{\tau, \xi} \Delta W_{\text{USA}}(\tau, \xi)^\rho \Delta W_{\text{CHN}}(\tau, \xi)^{1-\rho} \quad (26)$$

subject to $\Delta W_i > 0 \forall i$. Here, ΔW_i is the welfare change, in consumption-equivalent units, between staying in the initial BGP or signing the agreement and staying there forever, and $\rho \in (0, 1)$ is the bargaining power of the United States. I describe how to compute ΔW_i

later.

The result of the Nash bargaining exercise implies elimination of US tariffs on Chinese imports and an increase in the quality of IPR enforcement so that the domestic royalty fee increases to 25% while the foreign royalty fee increases to 11%.

The trade agreement is an unanticipated, permanent, one-time shock. I make two important assumptions that hold throughout the duration of the agreement: (i) There is perfect enforcement of the agreement, and (ii) the improvement in IPR applies both to foreign and domestic adopters, although the improvement may have different intensities. That is $\xi_{\text{CHN},n} \neq \xi_{\text{CHN},\text{CHN}}, \forall n \neq \text{CHN}$. These assumptions are motivated by current trade agreements that first require significant changes in the domestic legislation of participating countries that then translate into equal treatment of foreign firms.¹⁴

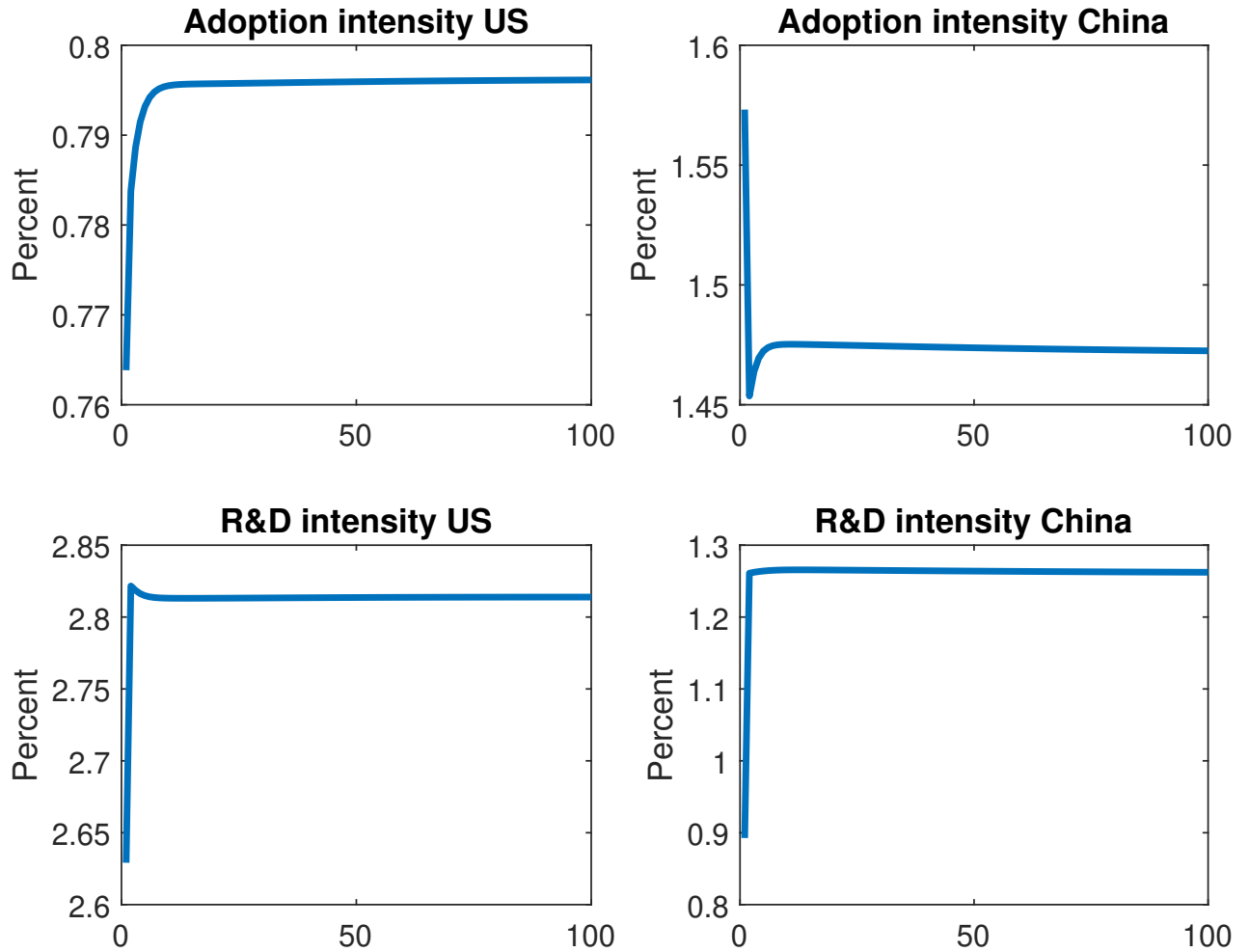
Then, I solve for the perfect foresight solution of the model, assuming that the economy starts on an initial BGP, which is calibrated to data for the year 2000. In period 1, China and the United States sign the trade agreement as the solution of the problem in equation (26). I then evaluate the impact of such a trade agreement on innovation, growth, and welfare.

Growth, Innovation, and Adoption The trade agreement has a positive effect on R&D intensity around the world through two channels. First, access to a larger market for Chinese exports increases domestic innovation in China. Second, an increase in IPR enforcement increases the return to innovators, both China and the United States, as innovators start receiving royalties for technologies that are adopted in China. Both countries reach a higher level of R&D intensity in the counterfactual BGP (Figure 1).

Adoption in China is subject to two opposing forces: (i) The return to Chinese adopters decreases, as they now have to pay royalties for technologies they were getting for free, but (ii) adopters profit from exporting intermediate products that are produced with licensed technology. The reallocation effect from adoption to innovation in China implies that, in the counterfactual BGP, R&D intensity is higher and adoption intensity is lower in China. In the United States, however, adoption intensity goes up: adopters benefit from more technologies being invented in China.

¹⁴For instance, the text of the Central America Free Trade Agreement (CAFTA), a NAFTA-style deal between the United States and five Central American nations (Guatemala, El Salvador, Honduras, Costa Rica, and Nicaragua), states that "each Party shall accord to nationals of the other Parties treatment no less favorable than it accords to its own nationals with regard to the protection and enjoyment of such intellectual property rights and any benefits derived from such rights".

Figure 1: 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 100 years following the signature of a trade agreement with IP provisions designed as Nash bargaining. Period 0 represents the initial BGP.

BGP Growth As a result of more innovation worldwide, the BGP growth rate increases from 1.85% to 1.93%. The left panel of Figure 2 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, China's productivity growth increases, overshooting the final BGP, as there is a large increase in innovation that is driven by both improved IPR protection and access to a larger export market. In the United States, the growth rate increases smoothly toward the final BGP. Both countries reach a BGP growth rate of 1.93% on the counterfactual BGP. Changes in growth rates are driven by the endogenous responses of innovation and adoption after changes in IP protection and trade costs. 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 2 shows.

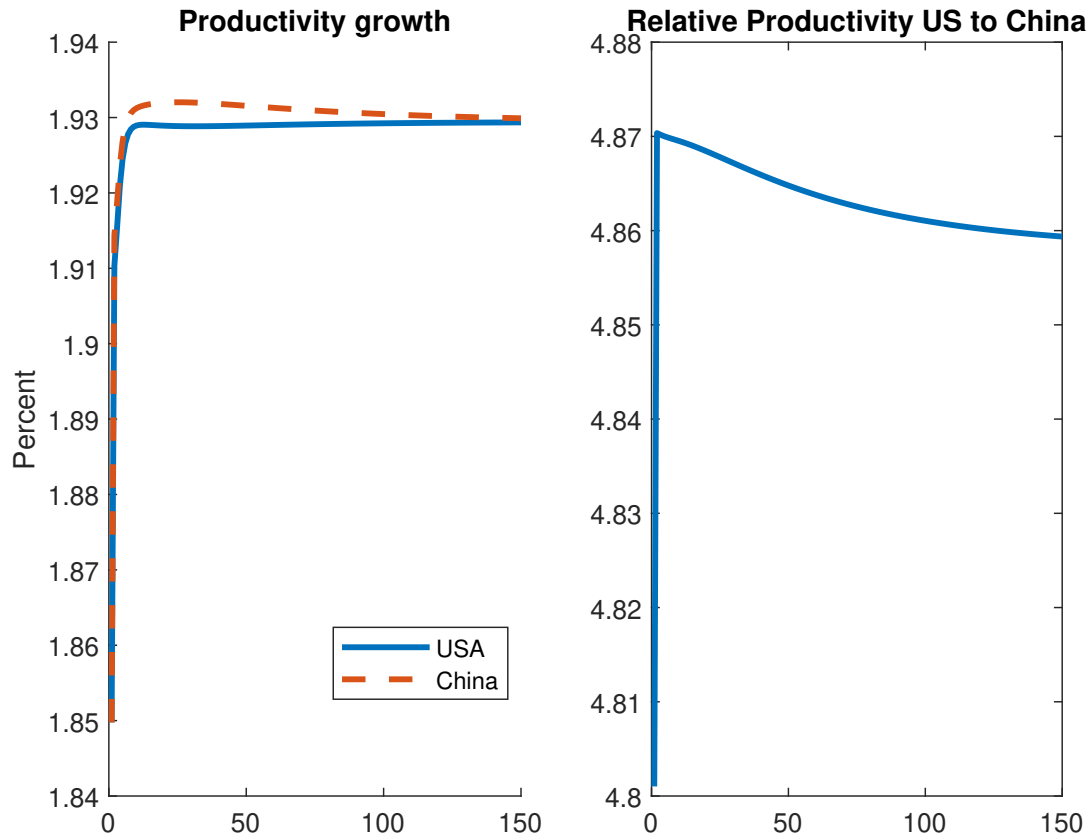
Trade and Royalties The decrease in export costs from China translates into a decrease in the US home trade share (Figure 3), so productivity increases through the standard channel present in static trade models.

The improvement in IP protection implies that China starts paying more royalties to domestic and foreign innovators for two reasons: (i) They pay higher prices for adopted technology, as they now have to pay royalties for technology they were previously getting for free, and (ii) they start receiving more foreign technology. Royalty payments from China to the United States increase (Figure 3). The United States also pays more royalties to China after signing the agreement, as China becomes more innovative: (i) The return to R&D in China increases through an improvement in IPR and through access to a larger export market, and (ii) there are spillover effects to the innovation process through an increase in foreign technologies being transferred to China. The two forces interact so that so that the technology trade imbalance between the United States and China becomes wider.

3.3 Welfare Analysis

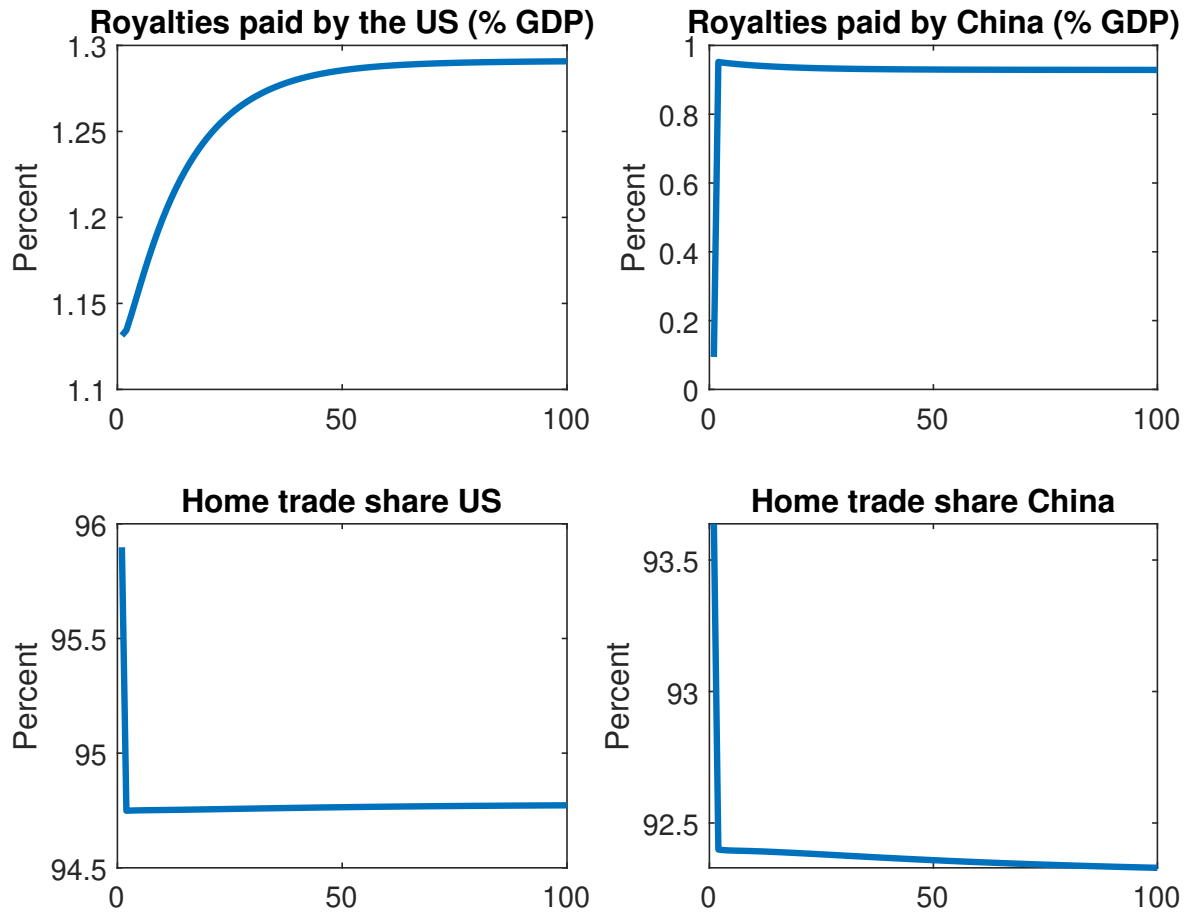
The results presented so far have implications for welfare. I compute welfare gains from IPR improvements accompanied by trade liberalizations in consumption-equivalent units. Denote λ_i , which corresponds to ΔW_i in equation (26), as the additional consumption the consumer needs every period to be indifferent between the baseline and counterfactual. Specifically,

Figure 2: Growth rate of productivity



Notes: The Figure plots 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.

Figure 3: Trade and royalty payments



Notes: The Figure plots the evolution of royalty payments made by the United States and China and their home-trade shares during the 100 years following the signature of a trade agreement with IP provisions designed as Nash bargaining. Period 0 represents the initial BGP.

welfare gains are computed as

$$\int_{t=0}^{\infty} \beta^t u \left(C_{it}^* \left(\frac{\lambda_i}{100} + 1 \right) \right) dt = \int_{t=0}^{\infty} \beta^t u(C_i) dt. \quad (27)$$

Evaluating welfare along the transition allows us to address the issue that BGP to BGP gains may be overstated, as 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, 2015).

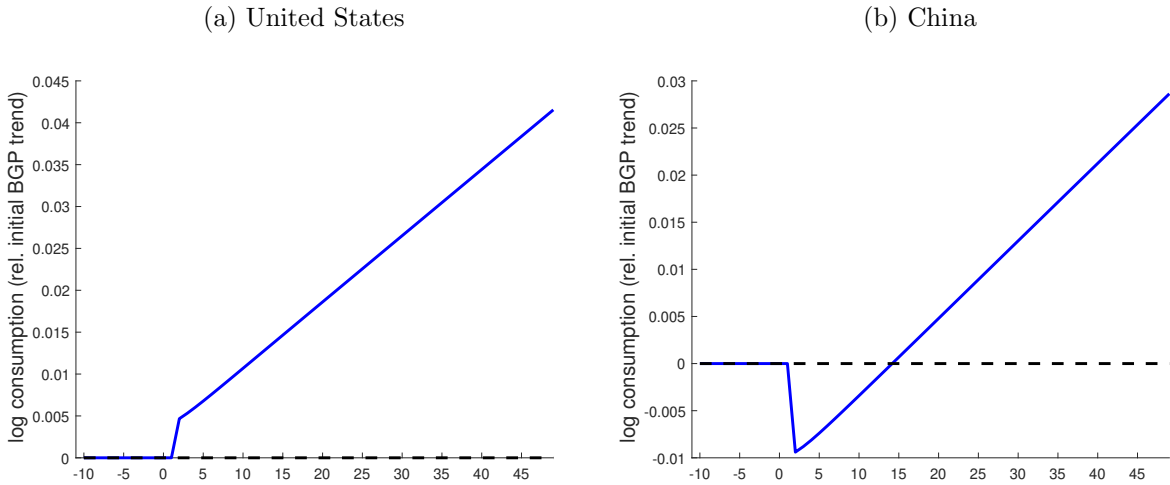
I find that all countries experience welfare gains from signing the agreement (first column of Table 2). The United States has the largest gains in consumption-equivalent units (2.17%), whereas China experiences the lowest gains (1.03%). Despite all countries experiencing positive gains overall, the 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.

Figure 4 shows the evolution of consumption per capita 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 1, 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 10 years after the initial shock, and China starts experiencing positive gains. The short-term losses in China from an improvement in its IPR are driven by the following channels: (i) Profits of adopters decrease as they have to pay more royalties, whereas profits of innovators increase as they receive more royalties. Because China has a comparative advantage in adoption versus innovation, overall profits go down, decreasing output; (ii) the increase in profits of innovators increases R&D spending. The decline in output together with the increase in investment in innovation decreases consumption in China in the short run.

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 increases growth to 1.93% (first column of Table 3), leading to long-term gains. The result is that it takes 10 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 4: 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.

Understanding the Mechanism 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. First, I consider the case in which China improves its IP protection but does not benefit from lower tariffs. Second, I consider an alternative scenario in which the United States lowers import tariffs from China, but China does not improve its IPR. Finally, I evaluate whether China has incentives to enter

a trade agreement with IP provisions beyond just reforming its domestic IPR unilaterally. Specifically, I conduct a counterfactual exercise in which China improves its domestic IPR but does not sign a trade agreement.

Table 2 reports welfare gains in each scenario. I find that both countries experience positive gains when there is an improvement in IPR, regardless of whether or not tariffs are reduced. However, the United States loses from reducing tariffs if China does not simultaneously improve its IPR. Finally, China gains from improving its domestic IPR, but the gains are larger if these reforms are part of a trade agreement with IP provisions. Hence, becoming part of a trade agreement gives China extra incentives to improve its domestic IP laws.

Table 2: Welfare Gains: Alternative scenarios

	Baseline	Only IPR	Only Trade	Dom. IPR (no agreement)
USA	2.17	3.85	-0.53	0.95
China	1.03	0.29	0.36	1.02

Notes: The table reports welfare gains from alternative policies: (1) Trade agreement with IP reforms and lower tariffs, (2) only IPR reform (both domestic and foreign), (3) only lower tariffs, and (4) improvement of domestic IPR (without trade agreement).

The results presented so far reflect both long-run and short-run effects. In the long run, the three alternative counterfactual exercises have an impact on growth. First, improving IPR increases innovation, and hence the BGP growth rate regardless of whether or not the United States lowers its tariffs to Chinese imports. However, the BGP growth rate increases more when tariffs are not eliminated: the growth rate increases from 1.85% to 1.98% in this case. Second, a reduction in US tariffs that is not accompanied by an improvement of IPR in China decreases the BGP growth rate from 1.85% to 1.83% (see Table 3). Here, US innovators decrease their R&D investment as they do not receive more royalty payments and firms face more competition from imitated products being imported from China. Finally, improving domestic IPR in China unilaterally increases the BGP growth rate to 1.88%, which represents a lower increase than when domestic reform occurs as a part of a trade agreement.

To evaluate the impact of the three alternative counterfactuals on the short run and along the transition, Figure 5 plots the log of consumption relative to the initial BGP consumption path in the three scenarios. The horizontal lines at zero represent the initial BGP, and the

Table 3: BGP growth: Alternative scenarios

	Baseline	Only IPR	Only Trade	Dom. IPR (no agreement)
Initial BGP	1.85	1.85	1.85	1.85
Final BGP	1.93	1.98	1.83	1.88

Notes: The table reports BGP growth rates from alternative policies: (1) trade agreement with IP reforms and lower tariffs, (2) only IPR reform (both domestic and foreign), (3) only lower tariffs, and (4) improvement of domestic IPR (without trade agreement).

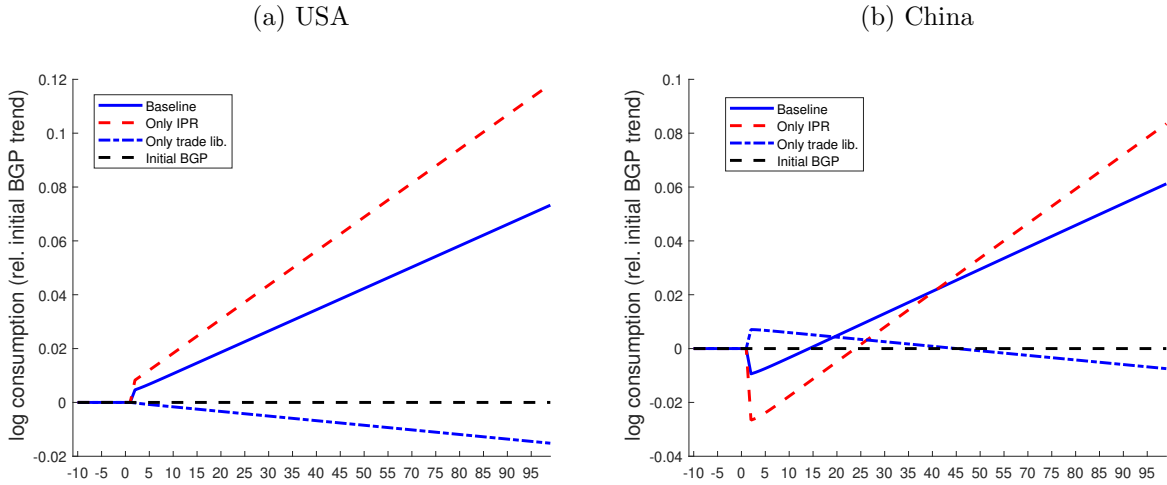
shock hits in period 1.

In the case when there is an improvement in IPR without a reduction in tariffs, welfare gains are positive for every country, but they are lower than in the baseline counterfactual for China. Along the transition, China experiences larger short-term losses than in the baseline scenario, which last for almost 20 years. These losses are driven by a larger initial drop in consumption and slower pace toward positive gains. Chinese investment in adoption decreases more than in the baseline counterfactual, as adopters cannot benefit from a larger market where they could sell the intermediate products produced with licensed technology. Profits of adopters decline more, leading to larger decreases in output and hence also in consumption. At the same time, innovators cannot take advantage of a larger market. Because growth rates increase in the long run (column 2 of Table 3), the initial losses convert into gains after several periods, leading to overall positive welfare gains. The United States experiences, as before, short-term and long-term gains. Short-term gains in the United States are larger than in the baseline: there is a larger initial increase in consumption when there is no lowering of tariffs, as the United States does not lose tariff revenue in this case.

Second, when there is trade liberalization without IPR improvement, the United States experiences losses and China experiences gains, although these gains are lower than in the baseline. Lower tariffs increase the return to adoption in China, as intermediate producers can sell their products to a larger market, which translates into higher profits and output. At the same time, Chinese adopters do not pay royalties for the use of foreign technology. As a result, there are positive short-term gains in China. In the United States, lower tariffs lead to a decline in the home trade share, increasing output and consumption. However, the US market faces more competition from Chinese imports produced with imitated technology, which decreases innovation incentives in the United States. These channels translate into negative short-term gains in the United States. Because US innovators are not compensated

from their R&D efforts, innovation and world growth decline, generating long-term losses.

Figure 5: Log of consumption relative to initial BGP trend: The Mechanism

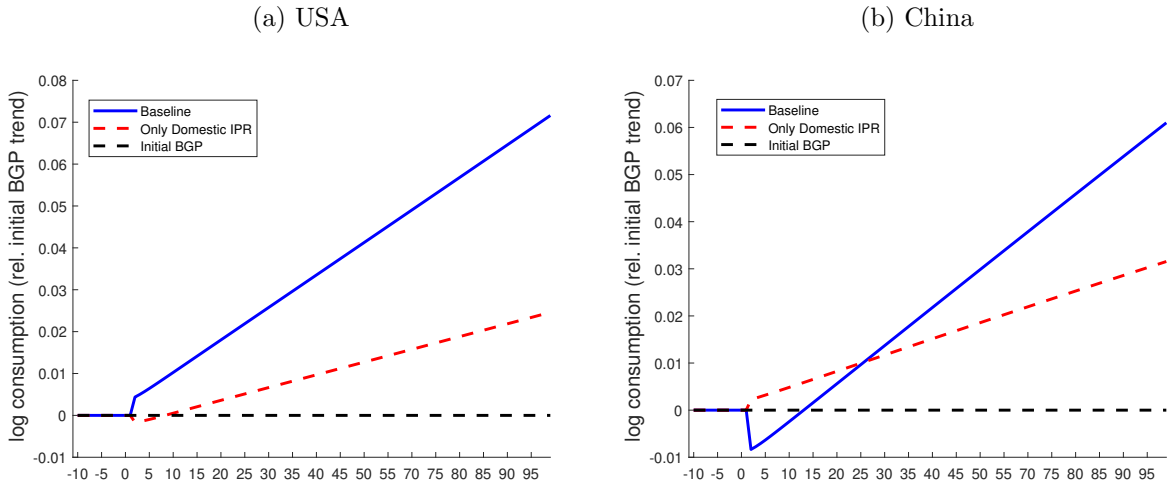


Notes: The figure plots the evolution of the log of consumption relative to its initial BGP trend in the United States (left panel) and China (right panel) 10 periods before and 50 periods after signing an agreement. The agreement is signed in period 1. The solid line represents the baseline trade agreement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

Finally, Figure 6 plots the evolution of consumption along the transition when China signs a trade agreement with the United States as in the baseline counterfactual and an alternative scenario in which China improves its domestic IPR without signing an agreement. Improving domestic IPR in China has positive long-term effects everywhere since China becomes more innovative and the world BGP growth rate increases from 1.85% to 1.88%. However, this increase is lower than when China improves IPR as part of a trade agreement (1.88% vs 1.93%). Short-term gains from reforming domestic IPR without a trade agreement are positive in China, since domestic innovators receive more royalties but adopters do not need to pay to foreign innovators. This result contrasts with the case in which China improves its IPR as part of a trade agreement. In that case, China suffered short-term losses. Overall, welfare gains in China are positive but slightly lower than with a signed agreement. An improvement of Chinese domestic IPR without a trade agreement generates short-term losses in The United States that last about 7 years. US innovators are not compensated for their

R&D efforts, and innovation goes down. The result is a lower BGP growth rate. These results imply that reforming IPR in China as part of a trade agreement has additional welfare effects for China. However, by signing an agreement, China goes through short-term losses, whereas improving domestic IPR without a signed agreement implies both short-term and long-term gains in China.

Figure 6: Log of consumption relative to initial BGP trend: Domestic IP Reform in China vs Trade Agreement with the United States



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 signing a trade agreement with IP provisions (solid line) and in the case in which China improves domestic IPR without being part of a trade agreement (dashed line). The agreement is signed in period 1.

Welfare-maximizing versus Politically-Motivated Government The trade agreement with IP provisions in equation (26) has been designed by a welfare-maximizing government, who chooses tariffs and level of IP protection to maximize welfare as calculated in consumption-equivalent units at the consumer's discount factor. By signing such a trade agreement, I found that both the United States and China gain overall, but China suffers short-term losses (see Figure 4). This agreement may not be attractive to a politically-motivated government that wants to minimize short-term losses in China. Here, I consider the design of a trade agreement made by a government with short-term objectives. Specifically, I assume the government has a lower discount factor than the consumer (i.e., 0.90

vs 0.96). I then compute the level of tariffs and quality of IP enforcement that solve the bargaining problem in equation (26), where welfare gains are computed at the government's discount factor. The new agreement implies a lower decline in US tariffs and a lower increase in Chinese royalty payments for foreign technology. Specifically, the new agreement consists of a reduction of US tariffs on Chinese imports of 80%, full improvement of domestic IPR in China, and an increase of China's foreign royalty fee from 1% to 10%. Compared to the main trade agreement, welfare gains in the United States are now lower, whereas China gains more overall (see Table 4). Both countries have positive gains in the short run (see Figure 7). On the one hand, when an agreement is designed by a politically motivated government, China agrees to improve foreign IP less than before, resulting in a lower increase of the BGP growth rate (1.93% in the welfare-maximizing agreement and 1.90% in the politically-motivated agreement). On the other hand, China pays less royalties abroad, which increases consumption in the short term. Hence, a politically-motivated government can reach a trade agreement where all countries gain both in the short and in the long run, at the expense of lower BGP growth, hence lower long-term gains.

Table 4: Welfare Gains: Welfare-maximizing vs politically-motivated agreement

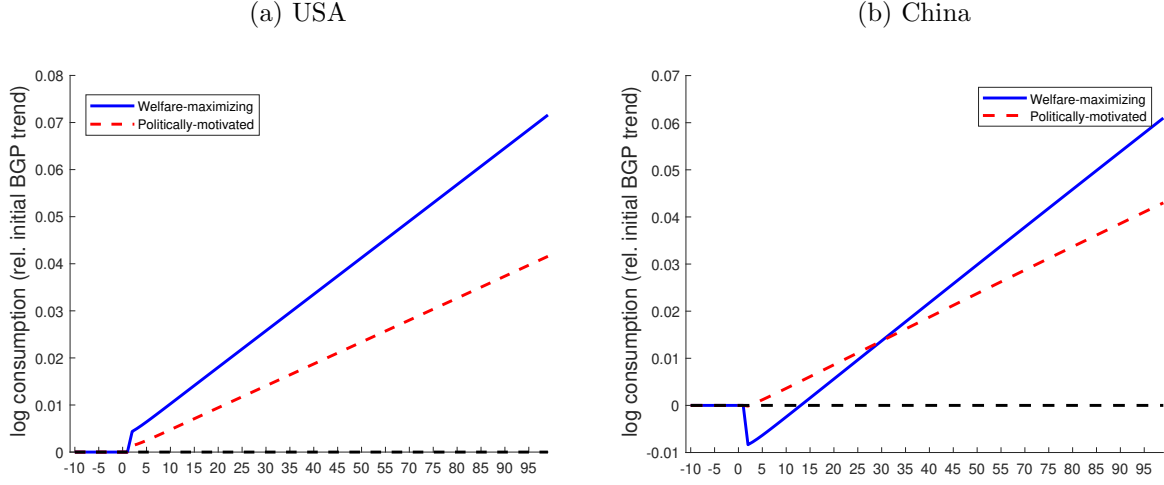
	Baseline	Only IPR
USA	2.17	1.11
China	1.03	1.15

Notes: The table reports welfare gains from trade agreements designed by: (1) welfare-maximizing government ($\beta = 0.96$); and (2) politically-motivated government ($\beta = 0.90$)

4 External Validation: Dynamics of International Licensing Following Deep Trade Agreements

One of the main implications of the model is that deep trade agreements with strict IP provisions increase royalty payments from developing to developed countries that sign such an agreement. However, trade liberalizations that reduce trade costs without requiring IP improvements have a non-negligible or negative effect on royalty payments. In this section, I study empirically the dynamics of international technology transfer following membership into RTAs with IP provisions. The main question of interest is, do trade agreements with

Figure 7: Log of consumption relative to initial BGP trend: Welfare-maximizing ($\beta = 0.96$) vs politically-motivated government ($\beta = 0.90$)



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 a welfare-maximizing government (solid line) or a politically-motivated government (dashed line). The agreement is signed in period 1.

IP provisions increase technology transfers from developed to developing economies?

The measure of technology transfer used throughout the analysis is technology licensing across countries (see Maskus, 2004, for a review of different types of technology transfer and the importance of licensing). I follow Santacreu (2021) and use data on bilateral royalty payments collected from the OECD Balanced Trade in Services dataset for 41 countries for 1995-2012. These data represent a more direct measure of technology diffusion than what has been typically used in the literature, such as international trade or foreign direct investment (FDI), because the transactions involved in international licensing leave a paper trail: These are contracts by which a patent owner (the inventor or exporter of the technology) licenses the right to use the patent to a foreign firm (the technology importer) in order to produce a good. In exchange for the license, the technology importer pays a royalty fee to the innovator. Technology licensing has become more important over time. While in the 1980s world royalty payments accounted for 0.06% of world GDP, this share was about 0.50% by 2019 (0.12% in 1995 and 0.40% in 2012).¹⁵ These numbers could be reflecting both an

¹⁵Data from World Development Indicators (WDI) World Bank.

increase in technology transfer in the world and an increase in payments for technology that previously was obtained for free. Hence, royalty payments are a form of technology transfer that is impacted by the quality of IPR enforcement. In the extreme case of pure imitation, firms do not pay any royalties to the innovator; in the other extreme of perfect enforcement of IPR, foreign firms pay royalties according to a previously stipulated fee. While several studies have found that improvements of IPR have a positive effect on technology licensing across countries (Branstetter, Fisman, and Foley, 2006), the dynamics of international technology licensing in the context of RTAs with IP provisions have not been studied yet. To do that, I follow the methodology developed by Martínez-Zarzoso and Chelala (2021), who compile a database of RTAs with technology transfer and innovation-related provisions from trade agreements that entered into force between 1995 and 2012. They decompose RTAs 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.

Before conducting a more rigorous econometric analysis, I show in Figure 8 the evolution of royalty payments from developing countries to developed countries during 1995-2012, before and after they signed an RTA agreement.¹⁶ RTAs with strict IP provisions are a way for developed countries to enforce IPR improvements in developing countries. 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).¹⁷ I restrict the attention to country-pairs involving a developed country sending technology to (i.e, receiving royalties from) a developing country. 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 or normalized royalty payments.

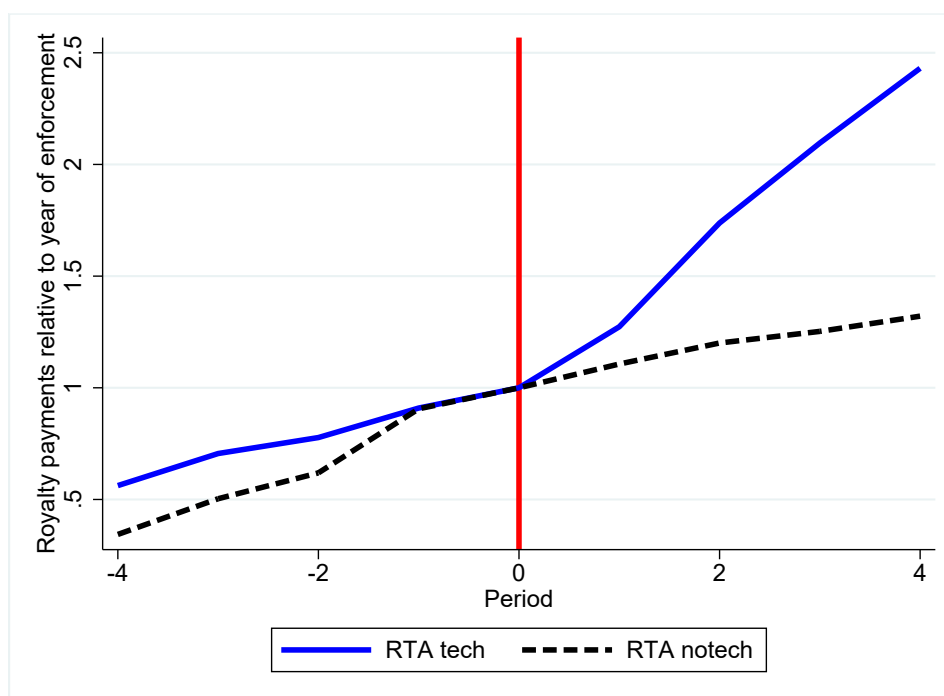
The figure shows a sharp increase in royalty payments from developing to developed countries following the year in which an RTA with IP provisions enters into force. In contrast, RTAs without IP provisions imply a slower rate of technology transfer to developing economies that sign such an agreement.¹⁸

¹⁶Developing countries are defined as those with a GDPpc \leq 12,500USD.

¹⁷There 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.

¹⁸In Appendix F I plot the dynamics of royalty payments for a sample of country-pairs.

Figure 8: 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 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.

Next, I conduct an econometric analysis to evaluate the effect of RTAs with IP provisions on technology transfer 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:

$$RP_{int} = \exp \left(\sum_{k=1} \text{RTA}_{int} + S_{nt} + F_{it} + fe_{in} \right) * u_{int}, \quad (28)$$

with RTA_{int} a free-trade agreement with technology provisions classified by Martinez-Zarzoso and Chelala (2021), S_{nt} exporter time, F_{it} importer time, and fe_{in} country-pair characteristics. I estimate equation (28) 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 consider two cases: (i) all 41 countries (1,640 country-pairs) and (ii) only country-pairs that involve a developed and a developing country. The results are reported in Table 5. 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) It includes observations from before and after an agreement enters into force, and (ii) it also includes country-pairs never signing any agreement during the period of analysis.

Table 5 shows that RTAs with both technology and non-technology provisions have a positive and statistically significant effect on bilateral royalty payments. That is, country-pairs that form RTAs, whether or not they contain strict IP chapters, share more technology. However, when I restrict the attention to country-pairs including a developed and developing country, only RTAs with technology provisions appear to be significant. In this case, the

Table 5: The effect of RTAs with IP provisions on international technology licensing

	Royalties		Trade	
	All	NS	All	NS
RTA tech	0.285*** (0.0490)	0.228*** (0.0533)	0.0376* (0.0166)	0.103*** (0.0287)
RTA notech	0.261*** (0.0646)	0.0830 (0.0685)	0.135*** (0.0218)	0.0103 (0.0418)
TRIPS	0.103 (0.127)	0.128 (0.0791)	0.0227 (0.0398)	0.00571 (0.0311)
N	28,458	14,544	28,484	14,596
Pseudo R^2	0.71	0.59	0.98	0.98

Notes: Standard errors in parentheses.

Clustered standard errors, clustered by exporter-importer (default).

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

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 the whole sample of countries (columns 1 and 3) and bilateral flows between a developed and a developing country (second and fourth columns).

results suggest that signing RTAs with IP provisions increases royalty payments between the countries by 25%.¹⁹ TRIPS does not have a significant effect when RTAs with IP provisions are considered.

It is important to make a few remarks about endogeneity of RTAs and reverse causality. One issue with the previous analysis is that RTAs may not be randomly assigned and instead are more frequently signed among countries that have strong trading relationships. The approach followed in the previous regressions used the methodology proposed by Baier and Bergstrand (2007), who overcome potential endogeneity by introducing bilateral time-invariant dummy variables. These pair fixed effects capture all unobserved heterogeneity associated with each country-pair relationship.²⁰ Moreover, as Maskus and Ridley (2021) mention, the concern of potential endogeneity in this type of agreement is limited by how

¹⁹ $[exp(\beta) - 1] * 100$.

²⁰In the appendix, I introduce leads of the dependent variable and show that the main empirical findings are preserved.

these agreements take place. Typically, strict IP provisions are required by one negotiating party, especially when these agreements are signed between a developed and a developing country, which happens quite frequently in the sample I use. Because developing countries have lower IPR enforcement than do developed economies, their agreement to improve IPR to get access to international markets is unlikely to be driven by any endogeneity of the trade policy.

The results are robust to estimating different specifications of the gravity regression. Following Baier and Bergstrand (2007), I consider (i) using 5-year intervals, (ii) including lags of RTAs to allow for technology transfer to have a delayed response to RTAs, (iii) including leads of the RTAs to test for potential endogeneity of the trade policy variable, and (iv) considering only those RTAs with IP provisions that refer to patents and IP improvement. The results are reported in Appendix A.

The empirical analysis suggests that countries entering into trade agreements with strict IP provisions experience an increase in royalty payments. IP provisions have a particularly positive impact on payments between developed and developing countries. The increase in royalty payments implies that (i) developing countries are receiving more foreign technology and (ii) developing countries are now paying for the technology they receive. While (i) may have positive effects on developing countries through higher innovation and growth, (ii) may have negative effects as firms in a developing country need to pay for technology they may have previously received at no cost.

5 Final Remarks

The paper develops a quantitative framework to analyze the interconnections between international trade and IPR. It introduces dynamics into a model of trade with endogenous innovation and international technology licensing as the main sources of productivity. The quantitative analysis along the transition allows me to disentangle between the short- and long-run effects of these policies. Imperfect IPR acts as a distortion in the economy, which is amplified by trade. Countries that improve their IPR gains, especially if they face lower tariffs when exporting goods produced with licensed technology. However, a trade liberalization that is not accompanied by IPR improvement creates long-term losses through lower incentives to innovate and higher competition.

The main 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. I leave these questions for future research.

References

- Akcigit, Ufuk, Sina T Ates, and Giammario Impullitti. 2018. “Innovation and trade policy in a globalized world.” Tech. rep., National Bureau of Economic Research.
- Arkolakis, Costas, Arnaud Costinot, and Andrés Rodríguez-Clare. 2012. “New trade models, same old gains?” *American Economic Review* 102 (1):94–130.
- Bagwell, Kyle, Robert W Staiger, and Ali Yurukoglu. 2020. ““Nash-in-Nash” tariff bargaining.” *Journal of International Economics* 122:103263.
- . 2021. “Quantitative analysis of multiparty tariff negotiations.” *Econometrica* 89 (4):1595–1631.
- Baier, Scott L and Jeffrey H Bergstrand. 2007. “Do free trade agreements actually increase members’ international trade?” *Journal of international Economics* 71 (1):72–95.
- Benhabib, Jess, Jesse Perla, and Christopher Tonetti. Forthcoming. “Reconciling models of diffusion and innovation: A theory of the productivity distribution and technology frontier.” Tech. rep.
- Branstetter, Lee, Ray Fisman, C Fritz Foley, and Kamal Saggi. 2011. “Does intellectual property rights reform spur industrial development?” *Journal of International Economics* 83 (1):27–36.
- Branstetter, Lee, Raymond Fisman, C Fritz Foley, and Kamal Saggi. 2007. “Intellectual property rights, imitation, and foreign direct investment: Theory and evidence.” Tech. rep., National Bureau of Economic Research.
- Branstetter, Lee G., Raymond Fisman, and C. Fritz Foley. 2006. “Do Stronger Intellectual Property Rights Increase International Technology Transfer? Empirical Evidence from

- U. S. Firm-Level Panel Data.” *Quarterly Journal of Economics* 121 (1):321–349. URL <http://www.jstor.org/stable/25098792>.
- Buera, Francisco J and Ezra Oberfield. 2019. “The Global Diffusion of Ideas.” *Econometrica* .
- Cai, Jie, Nan Li, and Ana Maria Santacreu. 2021. “Knowledge diffusion, trade and innovation across countries and sectors.” *American Economic Journal: Macroeconomics* .
- Celik, Levent, Bilgehan Karabay, and John McLaren. 2020. “Fast-track authority: A hold-up interpretation.” *Journal of International Economics* 127:103392.
- Diwan, Ishac and Dani Rodrik. 1991. “Patents, appropriate technology, and North-South trade.” *Journal of International Economics* 30 (1-2):27–47.
- Eaton, Jonathan and Samuel Kortum. 1996. “Trade in Ideas: Productivity and Patenting in the OECD.” *Journal of International Economics* 40 (3-4):251–278.
- . 1999. “International Technology Diffusion: Theory and Measurement.” *International Economic Review* 40 (3):537–570.
- . 2002. “Technology, Geography, and Trade.” *Econometrica* 70 (5):1741–1779.
- Ghironi, Fabio and Marc J Melitz. 2007. “Trade flow dynamics with heterogeneous firms.” *American Economic Review* 97 (2):356–361.
- Goldscheider, Robert, John Jarosz, and Carla Mulhern. 2018. “Use of the 25% rule in valuing intellectual property.” *Intellectual property: Valuation, exploitation, and infringement damages* :272–290.
- Grossman, Gene M. 2016. “The purpose of trade agreements.” In *Handbook of commercial policy*, vol. 1. Elsevier, 379–434.
- Grossman, Gene M and Elhanan Helpman. 1995. “Trade wars and trade talks.” *Journal of political Economy* 103 (4):675–708.
- Grossman, Gene M, Phillip McCalman, and Robert W Staiger. 2021. “The “New” Economics of Trade Agreements: From Trade Liberalization to Regulatory Convergence?” *Econometrica* 89 (1):215–249.

- Heathcote, Jonathan and Fabrizio Perri. 2002. “Financial autarky and international business cycles.” *Journal of Monetary Economics* 49 (3):601–627.
- Helpman, Elhanan. 1993. “Innovation, Imitation, and Intellectual Property Rights.” *Econometrica* 61:1247–80.
- Holmes, Thomas J, Ellen R McGrattan, and Edward C Prescott. 2015. “Quid pro quo: Technology capital transfers for market access in China.” *Review of Economic Studies* 82 (3):1154–1193.
- Hopenhayn, Hugo and Liyan Shi. 2020. “Knowledge creation and diffusion with limited appropriation.” Tech. rep., working paper.
- Juillard, Michel et al. 1996. *Dynare: A program for the resolution and simulation of dynamic models with forward variables through the use of a relaxation algorithm*, vol. 9602. CEPREMAP Paris.
- Kwan, Yum K and Edwin L-C Lai. 2003. “Intellectual property rights protection and endogenous economic growth.” *Journal of Economic Dynamics and Control* 27 (5):853–873.
- Lai, Edwin L-C. 1998. “International intellectual property rights protection and the rate of product innovation.” *Journal of Development Economics* 55 (1):133–153.
- Lai, Edwin L-C and Larry D Qiu. 2003. “The North’s intellectual property rights standard for the South?” *Journal of International Economics* 59 (1):183–209.
- Lind, Nelson and Natalia Ramondo. 2022. “Global Innovation and Knowledge Diffusion.” Tech. rep., National Bureau of Economic Research.
- Maggi, Giovanni and Ralph Ossa. 2021. “The political economy of deep integration.” *Annual Review of Economics* 13:19–38.
- Mandelman, Federico and Andrea Waddle. 2019. “Intellectual Property, Tariffs, and International Trade Dynamics.” *Journal of Monetary Economics* .
- Martínez-Zarzoso, Inmaculada and Santiago Chelala. 2021. “Trade agreements and international technology transfer.” Tech. rep.

- Maskus, Keith E and William Ridley. 2021. “Trade Impacts of Intellectual-Property-Related PTAs.” .
- Maskus, Keith Eugene. 2004. *Encouraging international technology transfer*, vol. 7. International Centre for Trade and Sustainable Development Geneva.
- Ossa, Ralph. 2011. “A “new trade” theory of GATT/WTO negotiations.” *Journal of Political Economy* 119 (1):122–152.
- . 2014. “Trade wars and trade talks with data.” *American Economic Review* 104 (12):4104–46.
- Perla, Jesse, Christopher Tonetti, and Michael E Waugh. 2015. “Equilibrium Technology Diffusion, Trade, and Growth.” Tech. rep., National Bureau of Economic Research.
- Ravikumar, B, Ana Maria Santacreu, and Michael Sposi. 2019. “Capital accumulation and dynamic gains from trade.” *Journal of International Economics* 119:93–110.
- Sampson, Thomas. 2019. “Technology gaps, trade and income.” .
- Santacreu, Ana Maria. 2015. “Innovation, diffusion, and trade: Theory and measurement.” *Journal of Monetary Economics* 75:1–20.
- . 2021. “International Technology Licensing, Intellectual Property Rights and Tax Havens.” .
- Silva, JMC Santos and Silvana Tenreyro. 2006. “The log of gravity.” *Review of Economics and Statistics* 88 (4):641–658.
- Somale, Mariano. 2021. “Comparative advantage in innovation and production.” *American Economic Journal: Macroeconomics* 13 (3):357–96.
- Tanaka, Hitoshi and Tatsuro Iwaisako. 2014. “Intellectual property rights and foreign direct investment: A welfare analysis.” *European Economic Review* 67:107–124.
- Van Patten, Diana and Esteban Méndez. 2022. “Voting on a Trade Agreement: Firm Networks and Attitudes Toward Openness.” Tech. rep., National Bureau of Economic Research.

- Waugh, Michael E. 2010. “International trade and income differences.” *American Economic Review* 100 (5):2093–2124.
- Yang, Guifang and Keith E Maskus. 2001. “Intellectual property rights, licensing, and innovation in an endogenous product-cycle model.” *Journal of International Economics* 53 (1):169–187.
- Yotov, Yoto V, Roberta Piermartini, José-Antonio Monteiro, and Mario Larch. 2016. *An advanced guide to trade policy analysis: The structural gravity model*. World Trade Organization Geneva.
- Zylkin, Thomas. 2018. “PPML_PANEL_SG: Stata module to estimate structural gravity models via Poisson PML.” .

APPENDIX

A Empirical Analysis: Robustness

5-Year Intervals

	Royalties		Trade	
	All	NS	All	NS
RTA tech	0.207** (0.0766)	0.199* (0.0936)	0.0585 (0.0314)	0.125** (0.0464)
RTA notech	0.216 (0.121)	0.0810 (0.151)	0.0685 (0.0402)	0.0666 (0.0829)
TRIPS	-0.221 (0.661)	0 (.)	0.581*** (0.154)	0 (.)
N	6,404	3,292	6,480	3,318
Pseudo R^2	0.70	0.58	0.98	0.98

Notes: Standard errors in parentheses.

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

Leads and Lags of the Trade Policy Variable

	All		NS	
RTA tech	0.284**	0.433***	0.202	0.370*
	(0.0899)	(0.109)	(0.109)	(0.188)
RTA notech	0.178	0.494***	0.243	0.454*
	(0.171)	(0.143)	(0.192)	(0.208)
TRIPS	-0.244	-0.341	0	0
	(0.670)	(0.620)	(.)	(.)
RTA tech (t-1)	-0.0168	0.712***	0.0890	0.629***
	(0.0713)	(0.216)	(0.103)	(0.182)
RTA notech (t-1)	0.282	0.166	-0.0627	0.0583
	(0.187)	(0.112)	(0.135)	(0.128)
RTA tech (t+1)		-0.413***		-0.376*
		(0.0884)		(0.159)
RTA notech (t+1)		0.00284		0
		(0.289)		(.)
<i>N</i>	4,797	3,124	2,466	1,610
Pseudo <i>R</i> ²	0.71	0.69	0.58	0.53

Notes: (SE) * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

As stated previously, 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. Table 6 shows the results when only patents and IP provisions are considered as part of an RTA with technology provisions. The results are consistent with those reported in Table 5. Patent- and IP-related provisions have a positive and statistically significant effect on royalty payments, both when the whole sample of countries is considered, as well as when I restrict attention to country-pairs consisting of a developed and a developing country. These results suggest that agreements requiring an improvement in IPR have a positive effect on technology transfer across member countries. As columns 3 and 4 show, these results also hold for international trade flows, as documented by Martínez-Zarzoso and

Chelala (2021).

Table 6: The effect of different subcategories of RTAs with IP provisions on international technology licensing

	Royalties		Trade	
	All	NS	All	NS
Patents and IP	0.305*** (0.0541)	0.292*** (0.0506)	0.0394* (0.0183)	0.0917** (0.0328)
RTA notech	0.280*** (0.0674)	0.128 (0.0669)	0.136*** (0.0221)	0.000153 (0.0427)
TRIPS	0.104 (0.128)	0.131 (0.0794)	0.0228 (0.0398)	0.00612 (0.0309)
N	28,458	14,544	28,484	14,596
pseudo R^2	0.71	0.59	0.98	0.98

Notes: Standard errors in parentheses.

Clustered standard errors, clustered by exporter-importer (default) .

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

B Derivations

Final Good Price Start from equation (3):

$$Y_{nt} = \left(\sum_{i=1}^M T_{it} x_{ni,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} . \quad (29)$$

From the demand of intermediate goods,

$$Y_{nt} = \left(\sum_{i=1}^M T_{it} \left(\left(\frac{\bar{m} W_{it} d_{ni} (1 + \tau_{ni})}{P_{nt}} \right)^{-\sigma} Y_{nt} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} , \quad (30)$$

where $\bar{m} = \frac{\sigma}{\sigma-1}$.

From here,

$$P_{nt} = \left(\sum_{i=1}^M T_{it} (\bar{m} W_{it} d_{ni} (1 + \tau_{ni}))^{1-\sigma} \right)^{\frac{1}{1-\sigma}}. \quad (31)$$

Trade share

$$\pi_{in,t} = \frac{X_{in,t}}{\sum_{i=1}^M X_{in,t}} = \frac{T_{nt} \left(\frac{\bar{m} W_{nt} d_{in} (1 + \tau_{in})}{P_{it}} \right)^{1-\sigma} P_{it} Y_{it}}{\sum_{k=1}^M T_{kt} \left(\frac{\bar{m} W_{it} d_{ik} (1 + \tau_{ik})}{P_{it}} \right)^{1-\sigma} P_{it} Y_{it}}, \quad (32)$$

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

From here,

$$\pi_{in,t} = \frac{T_{it} (W_{nt} d_{in} (1 + \tau_{in}))^{1-\sigma}}{\sum_{k=1}^M T_{kt} (W_{it} d_{ik} (1 + \tau_{ik}))^{1-\sigma}}. \quad (33)$$

The home trade share is then

$$\pi_{nn,t} = \frac{T_{nt} (W_{nt})^{1-\sigma}}{P_{nt}^{1-\sigma}}. \quad (34)$$

ACR formula Relative wages take the ACR formula

$$\frac{W_{nt}}{P_{nt}} = \frac{1}{\bar{m}} \left(\frac{T_{nt}}{\pi_{nn,t}} \right)^{\frac{1}{\sigma-1}}. \quad (35)$$

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:

$$\Pi_{it} = \sum_{m=1}^M \frac{\pi_{mi,t}}{1 + \tau_{mi}} P_{mt} Y_{mt} - W_{it} L_{it}, \quad (36)$$

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

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

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

Royalties are paid as a fraction of profits from country i , Π_{it} :

$$RP_{int} = \omega_{in,t} \Pi_{it}, \tag{37}$$

where $\omega_{in,t} = \frac{A_{in,t}}{T_{nt}}$ is the fraction of profits paid in royalties, and $T_{nt} = \sum_{n=1}^M A_{in,t}$.

Note that in the BGP (solving equations 9 and 12)

$$\omega_{in} \Pi_i = \frac{A_{in}}{T_i} \Pi_i = \frac{\varepsilon_{in}/g}{\varepsilon_{in} + g} \lambda_n \left(\frac{R_n}{Y_n} \right)^{\beta_r} \frac{T_n}{T_i} \Pi_i.$$

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

C Equations of the Model

Endogenous variables

$$\{Y_{nt}, P_{nt}, W_{nt}, C_{nt}, \Pi_{nt}, R_t, Z_{nt}, H_{nt}^r, T_{nt}, H_{in,t}^a, A_{in,t}, x_{in,t},$$

$$p_{in,t}, \pi_{in,t}, V_{nt}, J_{in,t}^{\text{innov}}, V_{in,t}^{\text{innov}}, J_{in,t}, V_{in,t}, \varepsilon_{in,t}, RP_{in,t}\}$$

Equations:

Resource constraint

$$P_{nt}Y_{nt} = P_{nt}C_{nt} + P_{nt}H_{nt}^r + P_{nt}H_{nt}^a$$

Prices

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

Price intermediate goods

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

Demand intermediate goods

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

Trade share

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

Value innovation

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

Profits firms

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

Value adopted

$$V_{in,t} = (1 - \chi_{in,t}) \frac{\Pi_{it}}{T_{it}} + \frac{1}{R_{it}} V_{in,t+1}$$

Value unadopted

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

Value adopted innovator

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

Value un-adopted innovator

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

FOC innovation

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

FOC adoption

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

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

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

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

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

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:

$$\hat{Y}_{nt} = \hat{C}_{nt} + \hat{H}_{nt}^r + \hat{H}_{nt}^a$$

In this expression, $\hat{X}_{it} = \frac{P_{it} X_{it}}{W_{Mt}}$. In this economy, the real wage grows at $Z_m^{\frac{1}{\sigma-1}}$. 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:

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

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

Demand intermediate goods:

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

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

Trade share:

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

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 $j_{in,t} = J_{in,t} T_{it} / W_{Mt}$.

Profits firms:

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

Value adopted:

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

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

Value unadopted:

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

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

Value adopted innovator:

$$\hat{v}_{in,t}^{\text{innov}} = \chi_{in,t} \hat{\Pi}_{it} + \frac{1}{r_t} \hat{v}_{in,t+1}^{\text{innov}} \frac{1}{1 + g_{P,it}} \frac{1}{1 + g_{T,it}}$$

Value un-adopted innovator:

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

FOC innovation:

$$\hat{H}_{nt}^r = \beta_r g_{Z,nt} \frac{\hat{Z}_{nt}}{\hat{T}_{nt}} \hat{v}_{nt}$$

FOC adoption:

$$\hat{H}_{in,t}^a \frac{\frac{\hat{T}_{it}}{\hat{A}_{in,t}} \varepsilon_{in,t}}{g_{in,t}^a} = \beta_a \frac{1}{r_{it}} \varepsilon_{in,t} \left[\hat{v}_{in,t+1} - \hat{j}_{in,t+1} \right] \frac{1}{1 + g_{P,it}} \frac{1}{1 + g_{T,it}}$$

Probability adoption:

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

Royalties:

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

Labor market-clearing condition:

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

Trade balance equation:

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

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:

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

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

Bond holdings

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

with $g_{c,t+1} = \hat{C}_{n,t+1}/\hat{C}_{nt} - 1 + \frac{1}{\sigma-1}g$. 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 $\{\beta, \eta, \beta_a, \beta_r, \sigma, \lambda_n, \bar{\varepsilon}_{in}, \xi_{in}, \chi_{in}, d_{in}, \tau_{in}, g\}$.

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 $H^a in$. Then I can use the 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.

$$r_n = \frac{1 + g/(\sigma - 1)}{\beta}$$

3.

$$P_n^{1-\sigma} = \sum_{i=1}^M T_i (\bar{m} \omega_i d_{ni} (1 + \tau_{ni}))^{1-\sigma}$$

4.

$$\pi_{in} = \frac{T_n (\bar{m}\omega_n d_{in}(1 + \tau_{in}))^{1-\sigma}}{P_i^{1-\sigma}}$$

5.

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

This can be written as

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

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

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 :

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

where

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

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

7.

$$v_{in} = \left(1 - \frac{1}{r_i} \frac{1}{1 + g_{pi}} \frac{1}{1 + g_{ti}} \right)^{-1} \Pi_i$$

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

$$\varepsilon_{in} = \bar{\varepsilon}_{in} \chi_i \left(\frac{H_{in}^a}{Y_i} \right)^{\beta_a} - g$$

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} :

$$j_{in} = \left(1 - \beta_a \varepsilon_{in} \frac{1}{r_i} \frac{1}{1 + g_{pi}} \frac{1}{1 + g_{ti}} - \frac{1}{r_i} \frac{1}{1 + g_{pi}} \frac{1}{1 + g_{ti}} (1 - \varepsilon_{in}) \right)^{-1} (1 - \beta_a) \varepsilon_{in} \frac{1}{r_i} \frac{1}{1 + g_{pi}} \frac{1}{1 + g_{ti}} v_{in}$$

10.

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

11.

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

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:

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

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

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

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 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 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 $\hat{T}_i = T_i/T_M$.

F International Licensing and RTAs with IP Provisions: Examples

Figure 9 shows the dynamics of royalty payments for a sample of country-pairs. There are two types of vertical lines: The one more to the left refers to when TRIPS was ratified by the developing country, and the other one refers to when the first RTA with technology provisions enters into enforcement.²¹ Consistent with the previous figure, RTAs with IP chapters seem to increase royalty payments from developing to developed economies, and the effect of these provisions is stronger than the minimum requirements established in TRIPS.

²¹Although TRIPS was established in 1995 as a requirement to be part of the WTO, many developing countries were granted an extension to meet the IP requirements, and in those countries the agreement was ratified after 1995.

Figure 9: Dynamics of International Technology Licensing During RTAs with IP Provisions

