Dynamic Gains from Trade Agreements with Intellectual Property Provisions*

Ana Maria Santacreu†

January 11, 2022

Abstract

I study the short- and long-term effects of trade agreements with strict intellectual property (IP) provisions on innovation, growth, and welfare. I develop a quantitative multi-country trade model with endogenous productivity through innovation and adoption that features imperfect IP rights enforcement. A counterfactual exercise shows that trade liberalization combined with improvements in IP protection increases welfare, innovation, and growth in the world. However, welfare gains along the transition accrue differently across countries. While developed countries benefit both in the short and in the long run from these agreements, developing countries experience short-run losses; these losses are amplified if IP improvement is not accompanied by trade liberalization. In contrast to findings from standard trade models, liberalizing trade without improving IP rights decreases welfare and innovation in the long run, making the distortion of imperfect IP protection worse.

Keywords: Technology Licensing; Deep Trade Agreements; Intellectual Property Rights

JEL Classification: F12, O33, O41, O47

---

*This version supersedes and 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, Sam Kortum, Jesse LaBelle and Fernando Leibovici for very insightful comments, and Jesse LaBelle for excellent research assistance. I also thank participants at Universitat Autonoma de Barcelona, Goettingen University, the Virtual Trade and Macroeconomics Workshop, the Federal Reserve Bank of Saint Louis, the University of Tokyo, the 2021 Ron Jones International Trade and Macroeconomics Workshop at the U of Rochester, and the North American Econometric Society Winter Meetings 2022. 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 concerned with removing trade barriers between member countries and required only minimum standards of IP enforcement. However, the scope of RTAs has changed over recent decades, including substantial IP provisions as part of their negotiations a majority of the time.[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. More recently, in August 2007 the United States under Section 301 of the US Trade Law and initiated an investigation on China's supposed misappropriation of IPR. The finding of several discriminatory IPR-related practices prompted the US administration to impose additional tariffs, ranging from 7.5% to 25%, on approximately $370 billion worth of U.S. imports from China.[2]

This paper studies, through the lens of a quantitative dynamic trade model, the short- and long-run implications for innovation, growth and welfare of changes in the nature of trade agreements. In particular, it addresses the following question: How do IP provisions in trade agreements interact with the traditional gains from trade liberalization? Traditionally, welfare gains from trade have been evaluated using static models (Arkolakis, Costinot, and Rodríguez-Clare, 2012). By nature, static models are not able to look at short- and medium-term effects of changes in trade policy. More recently, 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 path (BGP)—see Cai, Li, and Santacreu (2021); Somale (2018); Sampson (2019)—very few papers compute welfare gains along the transition (Akcigit, Ates, and Impullitti, 2018; Perla, Tonetti, and Waugh, 2015; Buera and Oberfield, 2019). Moreover, 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

[1]According to data for 437 RTAs listed in the WTO between 1948-2019 from the Design of Trade Agreements (DESTA) database, prior to 1995, only 20% of those included specific IP provisions, whereas after 2015, 95% of the agreements did (33 out of 35).

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

trade agreements have not been explored quantitatively.[3] This is the first paper that analyzes the short- and long-term dynamic gains from trade agreements with strict IP provisions.

I develop a quantitative Armington trade model of endogenous productivity through both innovation and technology adoption. Innovators invest resources to create new technologies; adopters invest resources to use a 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 the adoption intensity, adopters can use the technology to produce an intermediate good with monopolistic competition. In that case, adopters get 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 royalty fee is taken as given, but one can think that it is the result of a negotiation process in which the adopter and innovator split their surplus (see Benhabib, Perla, and Tonetti, Forthcoming). The model allows for imperfect enforcement of IPR by introducing a parameter that multiplies the royalty fee and reflects the quality of IP protection, ranging from pure imitation (no royalty payments, hence the parameter takes a value of zero) to perfect enforcement (royalty payments are paid as negotiated, hence the parameter takes a value of 1). Therefore, imperfect IP protection acts as a distortion in this economy, as innovators get less than what was previously stipulated by the royalty fee. I assume that countries cannot export the goods produced with imitated technology. Deep trade agreements are modeled as improvements in IPR that lower the distortion in return for access to export markets. I assume that there is perfect enforcement of these agreements and abstract away from a potential hold-up problem in which either China would make an upfront investment to improve its IP protection, but the United States would end up not lowering tariffs, or the United States would lower tariffs, but Chinese adopters would decide not to pay for royalties (see Celik, Karabay, and McLaren, 2020, for an example of a hold-up problem in trade agreements).

The model is calibrated to data on international trade flows, income, innovation, and royalty payments for three countries: the United States, China, and an aggregate rest of the world. Countries are heterogeneous in their innovation and adoption efficiency, the quality of IP protection, and geography and trade policy. I solve for the perfect foresight

[3] Other recent papers studying the interplay between openness and IP are Holmes, McGrattan, and Prescott (2015) who analyze the effect of quid-pro-quo practices in China on FDI and welfare, and Mandelman and Waddle (2019) who, in the context of the trade war between US and China, evaluate the effect that retaliatory tariffs have to prevent weakening of IP protection.

solution of the model following an unanticipated, permanent, one-time shock that consists of an improvement in IP protection in China, accompanied by a liberalization of its exports. Although China and the United States do not currently have a trade agreement with IP provisions, recent trade policy in the United States has been centered around accusations of IP misappropriation by China. In that sense, the goal of this exercise is to evaluate the welfare effects of potentially signing such an agreement.[4] Solving for the transitional dynamics of the model allows me to capture the dynamic effects of deep trade agreements and evaluate how welfare gains accrue along the transition.

The quantitative analysis shows that IPR reforms and trade liberalization interact in a non-trivial way to generate dynamic welfare gains. IPR reforms that are accompanied by trade liberalization increase innovation and growth in the long-run. Innovators, both in China and in the United States, receive royalties, which increases the return to R&D. Adopters in China are impacted in two ways: The return to adoption decreases as they now have to pay royalties; however, they have access to a larger market, which increases adoption incentives. A higher return to R&D drives growth up, and welfare increases in all countries. However, there are heterogeneous cross-country effects on how gains accrue along the transition. Developing countries experience short-term losses as, despite having access to a larger market, they now need to pay for technology that was previously imitated; developed countries, however, experience short-term gains as innovators receive more royalties and the return to innovation increases.

How do trade liberalization and IPR improvement interact to drive the results? I perform two counterfactual exercises to disentangle the main channels of the model. First, IP protection is reformed without a trade liberalization. In this case, all countries experience positive gains, but they are smaller than when there is also a trade liberalization. Moreover, China experiences a larger initial drop in consumption, as the standard forces of a trade liberalization are not present (and the United States experiences a lower initial increase in consumption). Therefore, improvements on IP protection are welfare improving whether or not they are accompanied by a trade liberalization; but, they are quantitatively larger when China can export its goods to the United States at lower cost. In a second counterfactual

[4] The United States has mechanisms in place to restrict imports from developing countries that incur in bad IP practices (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 Phase 1 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.

exercise, I assume a trade liberalization of Chinese exports to the United States, but there is imperfect enforcement of IP rights. In this case, there are short-term gains though standard static effects (Arkolakis, Costinot, and Rodríguez-Clare, 2012) in China, but dynamic losses though lower R&D investment and long-term growth. The reason is that, on the one hand, US innovators are not compensated by their efforts. Hence, R&D investment goes down and there is a decline in long-term growth. On the other hand, US firms face higher competition from products being exported by China though a trade liberalization, despite being produced with misappropriated technology. This effect reinforces the decrease in innovation and long-term growth, leading to long-term welfare losses.

The results suggest that imperfect IPR enforcement introduces a distortion in the economy, which is amplified by international trade. If there is a trade liberalization without IP rights improvement, every country loses. However, an improvement in IP protection ensures that incentives are correctly aligned and the policy is welfare improving. Hence the interaction between trade and IPR has important implications for welfare and growth that need to be studied through the lens of quantitative dynamic models of trade and growth.

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 the 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 channel of technology transfer in the model.

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

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

subject to the budget constraint

$$P_{nt}C_{nt} = W_{nt}L_{nt} + \Pi_{nt}^{\text{all}} - B_{nt} + R_{nt}B_{n,t-1}. \tag{2}$$

where β is the discount factor, W_{nt} is the wage, L_{nt} is population, Π_{nt}^{all} are the profits of all the firms in the economy, B_{nt} represents lending to innovators and adopters and R_{nt} is the interest rate.

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 CES production function

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

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

The demand for intermediate goods is given by

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

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 CRS production function

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

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

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

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

subject to equation (4).

International trade Intermediate products are traded internationally. Trade is Armington as varieties are differentiated both between varieties and across countries. Trade is costly and there are iceberg transport costs: 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. That means that, in equilibrium, $y_{nt}(j) = \sum_{i=1}^{M} x_{in,t}(j) d_{in}$.

The import share is given by

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

Real wages are given by the standard ACR expression

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

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^r_{nt}, to produce a new prototype or technology. Technologies arrive at a Poisson process given by

$$\lambda_n T_{nt} \left(\frac{H^r_{nt}}{\bar{Y}_t} \right)^{\beta_r}, \tag{8}$$

where $\lambda_n T_{nt}$ represents the efficiency of innovation, with λ_n as a country-specific parameter that captures innovation policy in the country, T_{nt} is the stock of knowledge available in country n at time t, $\bar{Y}_t$ is the world output, and β_r represents diminishing returns to adding one extra unit of final output into the innovation process.

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

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

Equation (9) implies that there is no depreciation of new ideas over time. Innovators have a monopoly over the technology, which they license to entrepreneurs who invest resources to make the technology usable. This process is called adoption. The value of an innovation is given by V_{nt}, and it will be defined later. The innovator chooses H^r_{nt} to maximize

$$\Delta Z_{nt} V_{nt} - P_{nt} H^r_{nt}. \tag{10}$$

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 in country i invests $h^a_{in,t}$ units of final output into adoption. With probability $\varepsilon_{in,t}(j)$ the adopter in country i is successful and can license the usable technology from country n by paying a licensing fee. The probability of adoption is given by

$$\varepsilon_{in,t}(j) = \bar{\varepsilon}_{in} \left(\frac{h^a_{in,t}(j)}{\bar{Y}_t} \right)^{\beta_a}. \tag{11}$$

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:

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

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 with that technology and pay a royalty fee to have the right to use the technology and make profits forever. 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 (PDV) of the share $\chi_{in,t}$ of profits made by intermediate producers in country i that use the technology; that is,

$$V^{\text{innov}}_{in,t}(j) = \chi_{in,t} \pi^i_{nt}(j) + \frac{1}{R_{nt}} V^{\text{innov}}_{in,t+1}(j).$$

where $\chi_{in,t}$ is the fraction of profits paid out in royalties, and $\pi^n_{it}(j)$ 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 $\chi_{in,t} = \bar{\chi}_{in,t} \xi_{in,t}$, with $\bar{\chi}_{in,t}$ representing a royalty fee that has been implicitly negotiated by the innovator in country n and the adopter in country i, and $\xi_{in,t}$ the quality of IP protection, ranging from 0 if there is pure imitation to 1 if there is perfect enforcement of IPR.[5]

[5] I 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.

The value for the innovator in country n of a non-yet adopted technology by adopters in country i is given by

$$J^{\text{innov}}_{in,t}(j) = \frac{1}{R_{nt}} \left[\varepsilon_{in,t} V^{\text{innov}}_{in,t+1}(j) + (1 - \varepsilon_{in,t}) J^{\text{innov}}_{in,t+1}(j)\right]$$

With probability $\varepsilon_{in,t}$ the technology is adopted and innovators receive profits forever, which is captured in $V^{\text{innov}}_{in,t+1}(j)$. 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 non-adopted technology.

Combining all the above expressions, the value of an innovator is the present discounted value of the share of intermediate producers' profits that operate with the innovator's technology, 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

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

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

$$P_{nt} H^r_{nt} = \beta_r \Delta Z_{nt} V_{nt}.$$

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

$$V_{in,t}(j) = (1 - \chi_{in,t}) \pi^n_{it}(j) + \frac{1}{R_{it}} V_{in,t+1}(j). \tag{13}$$

The value of a non-yet adopted prototype j that an adopter is trying to adopt is

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

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 $H^a_{in,t} =$

$\sum_{i=1}^{M}(Z_{nt} - A_{in,t-1})h^a_{in,t}$.

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

$$\varepsilon_{in,t} = \bar{\varepsilon}_{in}\left(\frac{H^a_{in,t}}{Y_{it}}\right)^{\beta_a}. \tag{15}$$

The FOC of adoption is

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

2.5 Market-Clearing Conditions

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

$$P_{nt}Y_{nt} = P_{nt}C_{nt} + P_{nt}H^r_{nt} + P_{nt}\sum_{i=1}^{M}H^a_{ni,t}. \tag{16}$$

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

$$W_{nt}L_{nt} = \sum_{i=1}^{M}T_{nt}W_{nt}l_{in,t} = \sum_{i=1}^{M}A_{in,t}W_{nt}x_{in,t}d_{in} = \sum_{i=1}^{M}T_{nt}\left(\frac{W_{nt}d_{in}}{P_{it}}\right)^{1-\sigma}P_{it}Y_{it}. \tag{17}$$

From the budget constraint of consumers we can derive an expression for net exports. Note that royalties are a trade service, so they will appear as part of net exports. Also note that there is no borrowing or lending with the rest of the world, so net exports are zero every period.

$$\sum_{i\neq n}^{M}T_{it}p_{ni,t}x_{ni,t} = \sum_{i\neq n}^{M}T_{nt}p_{in,t}x_{in,t} + \sum_{i=1}^{M}RP_{in,t} - \sum_{i=1}^{M}RP_{ni,t}. \tag{18}$$

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

2.6 Balanced Growth Path

I define the balanced growth path (BGP) of the economy as an equilibrium in which all variables grow at a constant rate. In the model, growth along 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.

Cross-country knowledge spillovers guarantee that the stock of knowledge T_n grows at the constant rate g, which is common across all countries; that is,

$$gT_i = \sum_{n=1}^{M} \frac{\varepsilon_{in}}{\varepsilon_{in} + g} \lambda_n T_n \left(\frac{H_n^r}{Y_n} \right)^{\beta_r}. \tag{19}$$

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}.

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.

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, and for 41 countries that are aggregated into three regions: the United Sates, China and an aggregate rest of the world. A quantitative exercise evaluates the effects on innovation, growth, and welfare of a trade agreement in which China needs to improve its IPR in return for access to exports to the US market. The exercise distinguishes between the short-term and long-term effects of this agreement, and perfect enforcement of such an agreement is assumed throughout the exercise. Then, to better understand how trade liberalization and IP reforms interact in driving the results, I evaluate the model under two alternative counterfactual scenarios: (i) China reforms its IP but there is not a trade liberalization; and (ii) China's exports to the United States are liberalized without reforming its IP.

3.1 Calibration

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 6%. The remaining parameters of the model are calibrated using data on trade flows, geography, R&D spending, income and royalty payments, together with gravity methods, in three steps. First, I calibrate trade costs and productivity, estimating a gravity equation of bilateral trade flows, following Waugh (2010). Second, I calibrate the diffusion parameters, estimating a 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.

Trade costs and relative productivity Using data on bilateral trade flows, geography and GDP per capita from CEPII for 2000, I calibrate iceberg transport costs d_{in} and productivity, $\Omega_n^{\sigma-1}T_n$, by running the following reduced-form regression, derived from manipulating equation (28) and taking logs:

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

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, maximum). The other control variables are in B_{ni}, and include common border effect, common currency effect, and regional trade agreement, between country n and country i. We include an exporter fixed effect, fe_n, which has been shown to fit better the patterns in both country incomes and observed price levels (see Waugh, 2010). Finally, $S_n = \Omega_n^{\sigma-1} T_n \left(\frac{\omega_n}{P_n}\right)^{1-\sigma}$. Using the estimated value for S_n, data on GDP per capita, and $\sigma = 5$, I recover $\Omega_n^{\sigma-1} T_n$ and obtain trade costs from the following expression:

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

The results are reported in th etop panel of Table 1.

Innovation and diffusion parameters I begin by calibrating the probability of adoption, ε_{in}, which is constant on the BGP. To calibrate its value, I first solve for an expression of royalty payments on the BGP. 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, we obtain an expression for royalty payments given by

$$RP_{in,t} = \frac{\varepsilon_{in}}{\varepsilon_{in} + g} \lambda_n T_{nt} \left(\frac{H_{nt}^r}{Y_t^w}\right)^{\beta_r} \Pi_{it} \tag{20}$$

Note that this expression resembles a gravity equation with exporter-time, importer-time and time-invariant bilateral fixed effects. Taking logs of 20,

$$\log(RP_{in,t}) = fe_{in} + S_{nt} + F_{it} \tag{21}$$

with $fe_{in} = \log\left(\frac{\varepsilon_{in}}{\varepsilon_{in}+g}\right)$, $S_n = \log\left(\lambda_n \frac{T_n}{T_i}\left(\frac{H_n^r}{Y_n}\right)^{\beta_r}\right)$, $F_i = \log\left(\frac{\Pi_i}{T_i}\right)$. I then estimate equation 21 as in Santacreu (2021) with PPML methods, using bilateral royalty payments as the dependent variable, and exporter-time, importer-time and country-pair fixed effects. I recover $\varepsilon_{i,n}$ from the bilateral fixed effects, assuming a productivity growth rate of 1.85%. The results are reported in the middle panel of Table 1.

The remaining parameters to calibrate are β_r, β_a, λ_n, and $\chi_{in,t}$. I calibrate β_r and λ_{nt} to match $g_y = 1.85\%$ and λ_n to match R&D intensity data using the algorithm developed by Cai, Li, and Santacreu (2021). Then I set $\beta_a = \beta_r$, since I do not have data on adoption spending, and recover $\bar{\varepsilon}_{in}$ to match ε_{in}.

Finally, I calibrate a value for the royalty fee $\bar{\chi}_{in}$ and the quality of IP rights ξ_{in} on the BGP. To set up a value for $\bar{\chi}_{in}$, I make the following assumptions:[6] First, I assume the royalty fee is lower for foreign adopters than for domestic adopters, which captures the idea that the bargaining power of domestic adopters is lower than that of foreign adopters. Second, and following this logic, I assume the domestic innovator and the domestic adopter split the surplus equally so that $\chi_{ii} = 0.50$. Third, I follow the 25% rule for the foreign royalty fee. This rule stipulates that a firm selling a product based on an innovator's intellectual property must pay that innovator a royalty of 25% of the gross profit made from the sale.[7] Hence, $\bar{\chi}_{in} = 0.25$ if $i \neq n$. To set up a value for the quality of IP protection, ξ_{in}, which is also the distortion in the economy and the policy parameter that will change in the counterfactual analysis, I assume that there is perfect enforcement of IP rights in the United States and the rest of the world so that $\xi_{in} = 1$ if $i = \{\text{US}, \text{ROW}\}$. However, Chinese adopters only pay one half of what is stipulated by $\bar{\chi}_{in}$ so that $\xi_{in} = 1/2$ if $i = \{\text{CHN}\}$. In that sense, there is partial enforcement of IPR in China.

3.2 Counterfactual Analysis: IPR Improvement and Trade Liberalization

I evaluate the effect that an increase in Chinese IP protection, in return for access to export markets, on innovation, growth, and welfare. I solve for the perfect foresight solution of the model following the unanticipated and permanent one-time shock.[8] The two policy parameters that are used in the counterfactual analysis are the trade costs, $d_{i,\text{China}}$, and the quality of IP protection, $\xi_{\text{China},n}$. The economy starts on the initial BGP, which is calibrated on data for 2000. In the initial BGP, there is imperfect IPR enforcement (i.e., $\xi_{\text{China},n} = 0.5$), so adopters pay half of what was implicitly negotiated by the 25% foreign rule and by the 50% domestic rule. Moreover, trade costs for Chinese exports are as calibrated to their 2000 values (See Table 1). In period 1, China signs a trade agreement with IP provisions that requires an improvement of its IPR in exchange for a reduction in export trade costs. In this case, (i) $\xi_{\text{CHN},\text{CHN}} = 1$, so royalties paid by China increase by 95% in the counterfactual BGP; and (ii) the iceberg transport costs decreases by half, so the Chinese export share

[6] This parameter could be endogenized as 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).

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

[8] The model is solved using Newton solution methods.

Table 1: Calibrated parameters

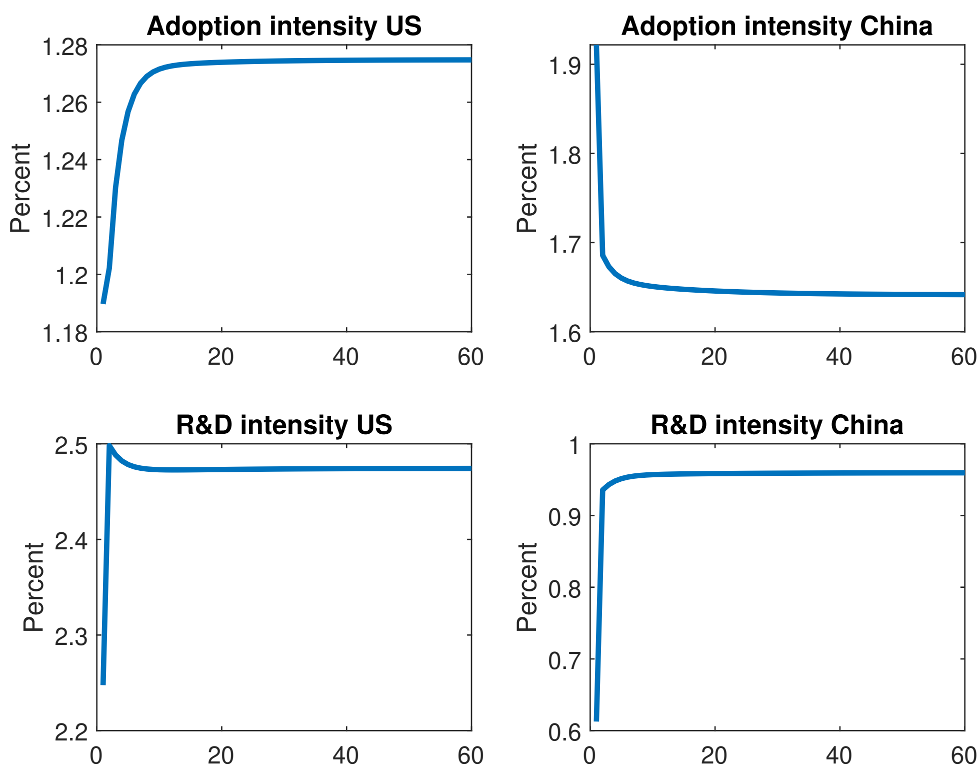
Parameter	Value	Source
$\Omega_{\text{US}}\,(T_{\text{US}})^{1/\sigma-1}$	6.25	Gravity trade
$\Omega_{\text{ROW}}\,(T_{\text{ROW}})^{1/\sigma-1}$	2.41	Gravity trade
$\Omega_{\text{China}}\,(T_{\text{China}})^{1/\sigma-1}$	1.00	Gravity trade
$d_{\text{USA,ROW}}$	2.73	Gravity trade
$d_{\text{USA,China}}$	2.95	Gravity trade
$d_{\text{ROW,USA}}$	6.23	Gravity trade
$d_{\text{ROW,China}}$	6.20	Gravity trade
$d_{\text{China,USA}}$	3.18	Gravity trade
$d_{\text{China,ROW}}$	2.90	Gravity trade
L_{US}/L_{China}	0.23	CEPII
L_{ROW}/L_{China}	1.33	CEPII
$\varepsilon_{\text{USA,ROW}}$	0.18	Gravity royalties
$\varepsilon_{\text{USA,China}}$	0.24	Gravity royalties
$\varepsilon_{\text{ROW,USA}}$	0.16	Gravity royalties
$\varepsilon_{\text{ROW,China}}$	0.14	Gravity royalties
$\varepsilon_{\text{China,USA}}$	0.18	Gravity royalties
$\varepsilon_{\text{China,ROW}}$	0.12	Gravity royalties
β_r	0.52	Match $g = 1.85\%$
β_a	0.52	Set $\beta_a = \beta_r$
λ_{US}	0.45	Match R&D intensity in USA
λ_{ROW}	0.40	Match R&D intensity in ROW
λ_{China}	0.29	Match R&D intensity in China
$\bar{\chi}_{in}$	0.25	Foreign royalty fee ($i \neq n$)
$\bar{\chi}_{ii}$	0.50	Domestic royalty fee
ξ_{in}	1.00	Perfect enforcement IP rights $i = \{\text{US}, \text{ROW}\}$
ξ_{in}	0.50	Partial enforcement of IP rights $i = \{\text{China}\}$

increases from 5% in the initial BGP to 13% in the counterfactual BGP. In this exercise, I assume that there is perfect enforcement of the agreement and abstract away from a hold-up problem of trade agreements.

Growth, Innovation, and Adoption The trade agreement with IP provisions 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. Second, an increase in IPR enforcement increases the return to innovators, both domestic and foreign, as they start receiving royalties for technologies that are adopted in China. Both countries reach a higher level of R&D intensity in the counterfactual BGP (see Figure 1).

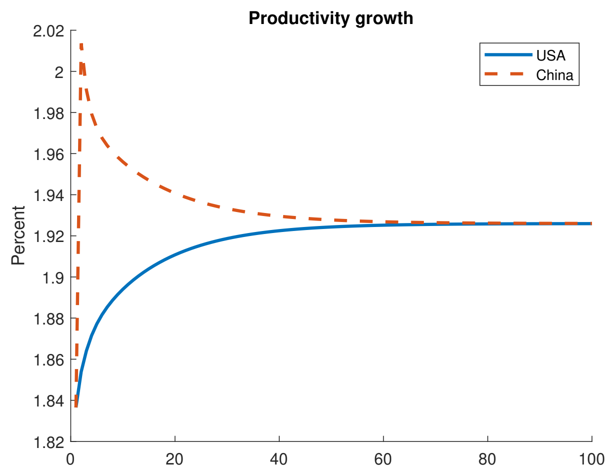
Adoption in China is subject to two opposing forces: (i) The return to Chinese adopters decreases as they now have to pay royalties for technologies they were getting for free, but (ii) adopters can now make profits from exporting intermediate products that are produced with licensed technology. The re-allocation effect from adoption into R&D in China implies that, in the counterfactual BGP, R&D intensity is higher and adoption intensity is lower. In the United States, however, both R&D and adoption intensities go up: Innovators get royalties from their R&D investments and adopters benefit from more technologies being invented in China and US adopters get access to m ore technologies through an increase in global innovation. Because final producers in the United States have access to Chinese technologies through a reduction in trade costs, prices go down. Indeed, there is an improvement in Chinese terms of trade and firms get more revenues from their exports.

Figure 1: R&D and adoption intensity



BGP Growth The BGP growth rate increases from 1.85% to 1.93%. Figure 2 shows the evolution of the productivity growth in the United States and in China. Both countries' productivity grows at the same rate on the BGP. In the first period, 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. Changes in growth rates are driven by the endogenous responses of innovation, adoption and international trade after changes in IP protection and trade costs.

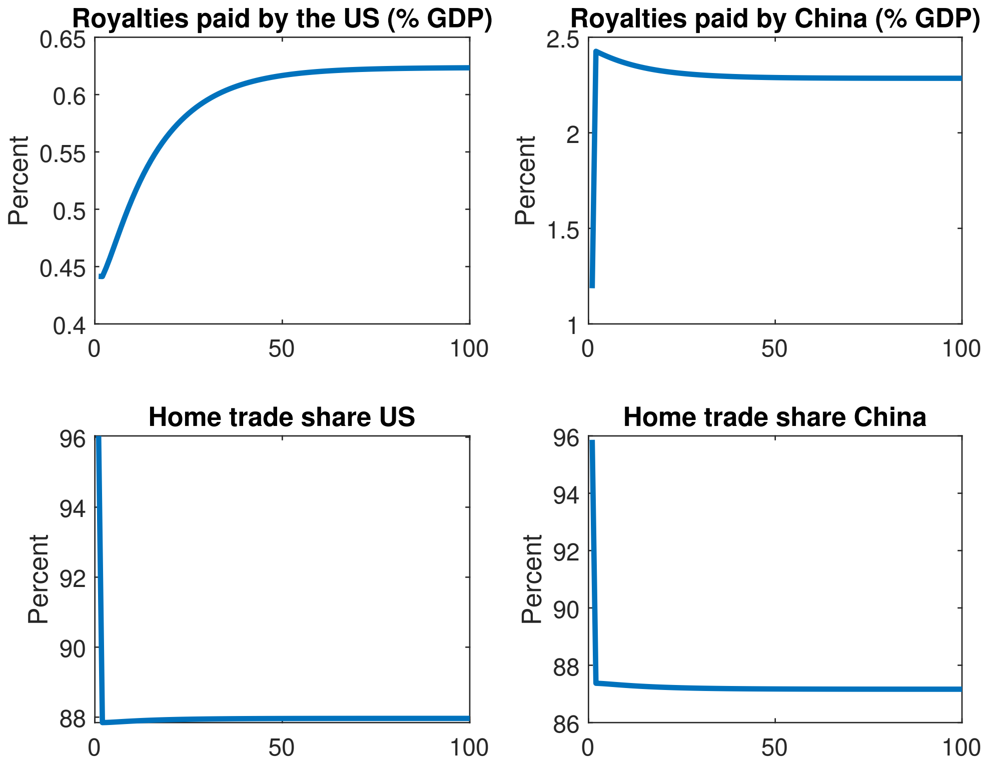
Figure 2: Growth rate of productivity



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

In the initial BGP, the United States has a surplus of technology (that is, it receives more royalties than it pays), whereas China has a deficit. The improvement in IP protection implies that China starts paying more royalties to domestic and foreign innovators for technology they were previously getting for free. In addition, they start receiving more foreign technology. Royalty payments from China to the US 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 though an increase in foreign technologies being transferred to China. The two forces interact so that the surplus of technology in the United States and the deficit in China become wider.

Figure 3: Trade and royalty payments



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 as the additional consumption the consumer needs every period to be indifferent between baseline and counterfactual. That is,

$$\int_{t=0}^{\infty} \beta^t u\left(C_{it}^{*}\left(\frac{\lambda_i}{100}+1\right)\right) dt = \int_{t=0}^{\infty} \beta^t u\left(C_i\right) dt \tag{22}$$

Evaluating welfare along the transition allows us to address the issue that steady-state 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).

We find that all countries experience welfare gains from trade liberalizations with IPR reforms (first column of Table 2). The United States has the largest gains in consumption-equivalent units (4.95%), whereas China experiences the lowest gains (2.34%). Despite all countries experiencing positive gains overall, the way these accrue during the transition is heterogeneous across countries. I analyze the short-term and long-term gains by analyzing the evolution of consumption in the United States and in China, following the shock.

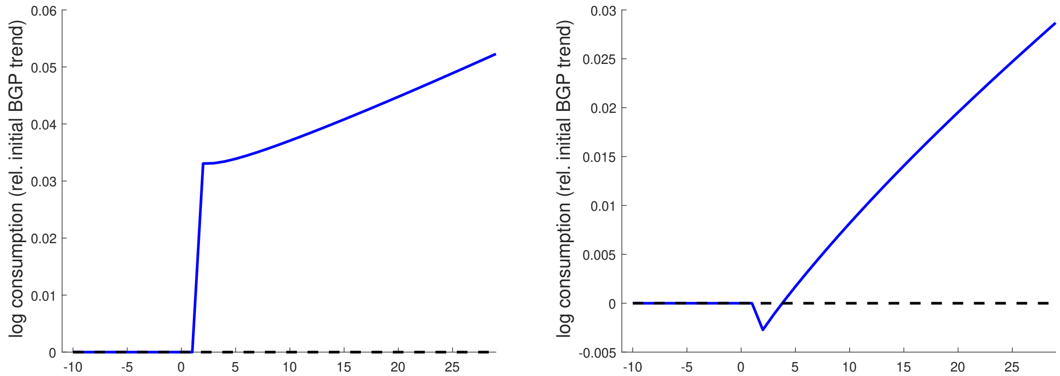
Figure 4 shows the evolution of consumption over time. The solid line in the two panels represents the log of consumption in the counterfactual—relative to the initial BGP consumption path. The horizontal line at zero represents the initial BGP. The shock hits in period 1. An improvement in IPR leads to a higher BGP growth rate in consumption both in the United States (left panel) and China (right panel), 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 3 years after the initial shock, and China starts experiencing positive gains then. 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 (fist column of Table 3), leading to long-term gains. The result is that it takes 3 years for higher BGP growth to replace previously "free" 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 in the 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 form China, and the home trade share decreases.

How do reforms in IP rights impact the gains from trade liberalization? To better understand the main channels at play, I analyze two alternative specifications of the model. First, I consider the case in which China improves its IP protection but does not benefit from trade liberalization. Second, I consider the case in which China gets access

Figure 4: Log of consumption

(a) United States (b) China



to export markets without improving its IP protection. The goal of these exercises is to understand how IPR reforms interact with traditional gains from trade liberalization along the transition.

Table 2 reports welfare gains in each scenario. We find that countries experience positive gains in all cases, being the highest in the baseline case, when IPR reforms are accompanied by trade liberalization. Welfare gains are the lowest when there is only trade liberalization without IPR reforms.

Table 2: Welfare Gains: Alternative scenarios

	Baseline	Only IPR	Only Trade
USA	4.95	3.03	1.00
ROW	2.58	2.78	-0.98
China	2.34	0.063	1.53

Next, I analyze the main channels driving the differences in welfare results across the two exercises. I evaluate how welfare gains accrue along the transition in each case by plotting the log of consumption relative to the initial BGP consumption path (see Figure 5). The horizontal line at zero represents the initial BGP, and the shock hits in period 1.

In the case when there is an improvement in IPR without trade liberalization, welfare gains are positive for every country, but they are lower than in the baseline counterfactual. The United States experiences larger gains that China. Along the transition China experiences larger short-term losses than in the baseline scenario, which last for almost 25 years.

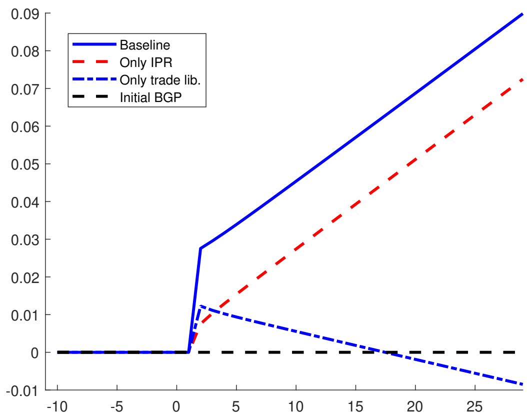
This is driven by a larger initial drop in consumption and slower pace toward positive gains. Moreover, short-term gains in the United States are lower. Despite reaching an almost identical BGP growth rate as in the baseline case (column 2 of Table 3), there is a lower initial increase in consumption when there is no trade liberalization. An improvement inf IPR that is not met by trade liberalization decreases investment in adoption even more in China, as adopters cannot benefit from a larger market where they sell the intermediate products that are produced with licensed technology. Profits of adopters decline more, leading to larger decreases in output, hence consumption. At the same time, innovators cannot take advantage of a larger market. In the United States, final producers do not have access to more varieties from China, and its home trade share does not decrease. Hence the initial increase in output and consumption is lower. 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 most interesting and less trivial case is when there is trade liberalization without IPR improvement. Here, both the United States and China gainwith China experiencing larger gains. Different from the other cases, both countries gain in the short-run, but there ar elong-term losses through a decrease in the BGP growth rate (see Table 3). A trade liberalization increases the return to adoption in China, as intermediate producers can sell their products to a larger market. That translates into higher profits and output. In the United States, lower import trade costs lead to a decline in the home trade share, increasing output and consumption. These channels imply positive short-term gains. Positive short-term gains in China are larger than when there are IPR improvements, as adopters do not need to pay more royalties to innovators. On the contrary, short-term gains in the United States are lower than in the previous counterfactual exercises as innovators do not receive more royalty payments and there is an increased competition from China, which is selling goods produced with imitated technology. As a result, US innovators are not compensated from their R&D efforts, which decreases innovation and world growth.

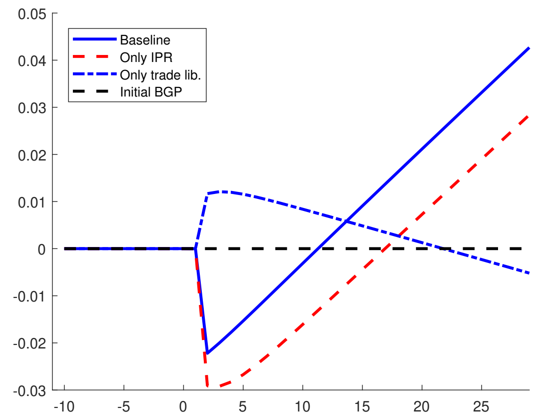
In summary, the distribution of welfare gains across countries is very different from trade cost versus IPR policy changes. The United States benefits more from IP protection, whereas China benefits more from lower trade costs. However, both countries benefit more from combined changes in the two policy variables. These results suggest that imperfect IPR enforcement introduces a distortion in the economy, which is amplified by international

Figure 5: Log of consumption relative to initial BGP trend

(a) USA



(b) China



trade. If there is trade liberalization without IPR improvement, every country loses in the long-run. However, with an improvement in IPR every country gains. An improvement in IP protection ensures that incentives are correctly aligned and that the policy is welfare improving. Hence the interaction between trade and IPR has important implications for welfare and growth that need to be studied through the lens of quantitative dynamic models of trade and growth.

Table 3: BGP growth: Alternative scenarios

	Baseline	Only IPR	Only Trade
Initial BGP	1.85	1.85	1.85
Final BGP	1.93	1.95	1.83

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

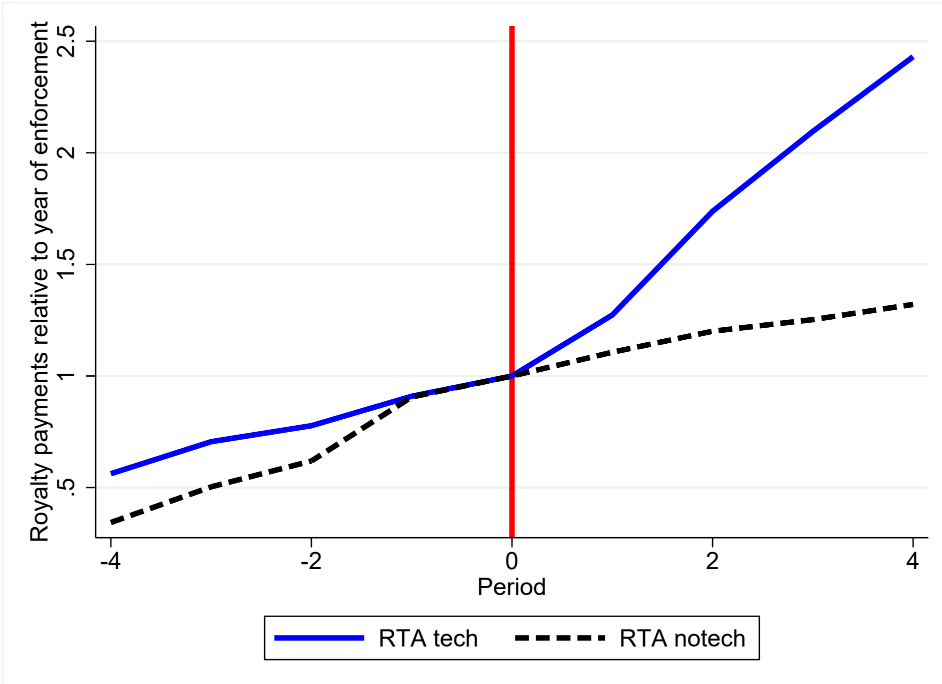
One of the main implications of the model is that deep trade agreements with strict IP provisions increase royalty payments from developing to developed countries signing the agreement. However, trade liberalizations that reduce trade costs without requiring IP improvements have a non-negligible or negative 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 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 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).[9] These numbers could be reflecting both an 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 in 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 has 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 have 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) intellectual property.

Before conducting a more serious econometric analysis, I show in Figure 6 the evolution

[9] Data from WDI World Bank.

Figure 6: Dynamics of International Technology Licensing During RTAs with IP Provisions



of royalty payments from developing countries to developed countries during 1995-2012, before and after they signed an RTA agreement.[10] RTAs with strict IP provisions are a way for developed countries to enforce IPR improvements by 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).[11] I restrict the attention to country-pairs involving a developed country sending technology to (i.e, receiving royalties) a developing country. Royalty payments are normalized to one 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 agreement with IP provisions enters into force. Instead, RTAs without IP provisions imply a slower rate of technology transfer to developing economies signing the agreements.[12]

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

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

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

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

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:

$$RP_{int} = \exp\left(\sum_{k=1} \text{RTA}_{int} + S_{nt} + F_{it} + fe_{in}\right) * u_{int}. \tag{23}$$

with RTA_{int} as a free trade agreement with technology provisions as classified by Martinez-Zarzoso and Chelala (2021), S_{nt} as exporter-time, F_{it} as importer-time, and fe_{in} as country-pair characteristics. I estimate equation 23 using PPML methods, as it has been 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 us 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 4. 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 the agreement enters into force, and (ii) it also includes country-pairs never signing any agreement during the period of analysis.

Table 4 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 we 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 results suggest that signing RTAs with IP provisions increases royalty payments between the

Table 4: The effect of RTAs with IP provisions on international technology licensing

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

Standard errors in parentheses
Clustered standard errors, clustered by exporter-importer (default).
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

countries by 25%.[13] 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.[14] Moreover, as Maskus and Ridley (2021) mention, the concern of potential endogeneity in this type of agreement is limited by how 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.

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

[14] In the Appendix, I introduce leads of the dependent variable and show that the main empirical findings are preserved.

The results are robust to estimating different specifications of the gravity regression. Following Baier and Bergstrand (2007), we 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 or 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 though higher innovation and growth, (ii) may have a negative effect 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 intellectual property rights. It introduces dynamics into a model of trade with endogenous innovation and adoption as the main sources of productivity. Adopters pay royalties to the innovators for the right to use their technology. The analysis allows me to disentangle between the short- and long-run effects of these policies. A quantitative exercise shows that imperfect IPR act as a distortion in the economy, which is amplified by trade. Countries that improve their IPR gain, especially if they can export the goods produced with licensed technology. However, in the case of a trade liberalization that is not accompanied by IPR improvement, every country loses.

The main results have implications for optimal policy, as the interactions between trade and IPR suggest that both policies can be used simultaneously to reach a first-best solution. Moreover, the analysis abstracts from imperfect enforcement of trade agreements with IP provisions, which may lead to a hold-up problem. 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.

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." *The 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. 1999. "International Technology Diffusion: Theory and Measurement." *International Economic Review* 40 (3):537–570.

———. 2002. "Technology, Geography, and Trade." *Econometrica* 70 (5):1741–1779.

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." *The 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.

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.

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.

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. 2021. "International Technology Licensing, Intellectual Property Rights and Tax Havens." .

Silva, JMC Santos and Silvana Tenreyro. 2006. "The log of gravity." *The Review of Economics and Statistics* 88 (4):641–658.

Somale, Mariano. 2018. "Comparative Advantage in Innovation and Production." Tech. rep., Mimeo.

Tanaka, Hitoshi and Tatsuro Iwaisako. 2014. "Intellectual property rights and foreign direct investment: A welfare analysis." *European Economic Review* 67:107–124.

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

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)		(.)
N	4,797	3,124	2,466	1,610
Pseudo R^2	0.71	0.69	0.58	0.53

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

As stated previously, technology-related RTAs could take several forms, from 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 5 shows the results when only patents and IP provisions are considered as part of the RTA tech agreements. The results are consistent with those reported in Table 4. Patents 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 we 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 has been documented by Martínez-Zarzoso and Chelala

(2021).

Table 5: The effect of different sub-categories of RTAs with IP provisions on international technology licensing

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

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)

$$Y_{nt} = \left(\sum_{i=1}^{M} T_{it} x_{ni,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{24}$$

From the demand of intermediate goods

$$Y_{nt} = \left(\sum_{i=1}^{M} T_{it} \left(\left(\frac{\bar{m} W_{it} d_{ni}}{P_{nt}} \right)^{-\sigma} Y_{nt} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{25}$$

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

From here

$$P_{nt} = \left(\sum_{i=1}^{M} T_{it} \left(\bar{m} W_{it} d_{ni} \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \tag{26}$$

Trade share

$$\pi_{in,t} = \frac{X_{in,t}}{\sum_{i=1}^{M} X_{in,t}} = \frac{T_{nt} \left(\frac{\bar{m} W_{nt} d_{in}}{P_{it}} \right)^{1-\sigma} P_{it} Y_{it}}{\sum_{k=1}^{M} T_{kt} \left(\frac{\bar{m} W_{it} d_{ik}}{P_{it}} \right)^{1-\sigma} P_{it} Y_{it}} \tag{27}$$

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

From here

$$\pi_{in,t} = \frac{T_{it} \left(W_{nt} d_{in} \right)^{1-\sigma}}{\sum_{k=1}^{M} T_{kt} \left(W_{it} d_{ik} \right)^{1-\sigma}} \tag{28}$$

The home trade share is then

$$\pi_{nn,t} = \frac{T_{nt} \left(W_{nt} \right)^{1-\sigma}}{P_{nt}^{1-\sigma}} \tag{29}$$

ACR formula

$$\frac{W_{nt}}{P_{nt}} = \frac{1}{\bar{m}} \left(\frac{T_{nt}}{\pi_{nn,t}} \right)^{\frac{1}{\sigma-1}} \tag{30}$$

Using the equation for prices we can show that the ACR formula becomes

$$\frac{W_{nt}}{P_{nt}} = \frac{1}{\bar{m}} \left(\frac{T_{nt}}{\pi_{nn,t}} \right)^{\frac{1}{\sigma-1}} \tag{31}$$

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

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 for the domestic and export market.

$$\Pi_{it} = T_{it} \sum_{m=1}^{M} \pi_{mi,t} \tag{32}$$

where $\sum_{m=1}^{M} \pi_{mi,t} = \sum_{m=1}^{M} p_{mi} x_{mi} - W_{it} L_{it} = \sum_{m=1}^{M} \bar{m} W_i d_{mi} l_{mi} / d_{mi} - W_{it} L_{it} = (\bar{m} - 1) W_{it} L_{it}$

Then,

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

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

- Innovators

$$\sum_{i=1}^{M} RP_{in,t} - P_{nt}H^r_{nt}$$

- Adopters and intermediate producers

$$-P_{nt}\sum_{i=1}^{M} H^a_{in,t} + \Pi_{nt} - \sum_{i=1}^{M} RP_{ni,t}$$

  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}:

$$RP_{int} = \omega_{in,t}\Pi_{it} \tag{33}$$

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 equation 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

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

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

Equations

Resource constraint

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

Prices

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

Price intermediate goods

$$p_{in,t} = \bar{m} W_{nt} d_{in}$$

Demand intermediate goods

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

Trade share

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

Value innovation

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

Profits firms

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

Value adopted

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

Value un-adopted

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

Value adopted innovator

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

Value un-adopted innovator

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

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 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

$$L_{nt} = \sum_{i=1}^{M} T_{nt}\left(\frac{W_{nt}d_{in}}{P_{it}}\right)^{-\sigma} Y_{it}$$

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

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

Transforming the interest rate in real terms

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

Total number of adopted technologies

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

D Stationary Variables

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

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

Resource constraint

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

In this expression, $\hat{X}_{it} = \frac{P_{it}X_{it}}{W_{Mt}}$. 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 EK model, we get something similar where $\theta = \sigma - 1$.

Prices

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

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

Demand intermediate goods

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

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

Trade share

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

Value innovation

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

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

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 un-adopted

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

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

Value adopted innovator

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

Value un-adopted innovator

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

FOC innovation

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

FOC adoption

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

Probability adoption

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

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

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

Law of motion of innovation

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

Law of motion of adoption

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

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

Interest rate

$$r_{nt} = \frac{1}{\beta}(1 + g_{c,t+1})$$

with $g_{c,t+1} = \hat{C}_{n,t+1}/\hat{C}_{nt} - 1 + \frac{1}{\sigma-1}g$

Total number of adopted technologies

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

E BGP

The parameters of the model are $\{\beta, \beta_a, \beta_r, \sigma, \lambda_n, \bar{\varepsilon}_{in}, \xi_i, d_{in}, g\}$.

To solve for the BGP, we 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 we 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^a_{in}, g and T_n

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

3.

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

4.

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

5.

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

This can be written as

$$\omega_n L_n = \sum_{i=1}^{M} \pi_{in} Y_i$$

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

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

$$\sum_{i \neq n}^{M} \pi_{ni} Y_n = \sum_{i \neq n}^{M} \pi_{in} Y_i + \sum_{i=1}^{M} rp_{in} - \sum_{i=1}^{M} rp_{ni}$$

where

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

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

7.

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

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

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

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

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

9. 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. $$H^r_n = \left(\beta_r V_n \lambda_n Y_n^{-\beta_r}\right)^{1/(1-\beta_r)}$$

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

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

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

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

13. Plug into the FOC for adoption and update H^a_{in}.

14. Use the trade balance equation to update wages. If there are M countries, we need $M-1$ updating equations because one 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 to that eigenvalue gives T, which is unique up to a scalar. So we can just compute $\hat{T}_i = T_i / T_M$.

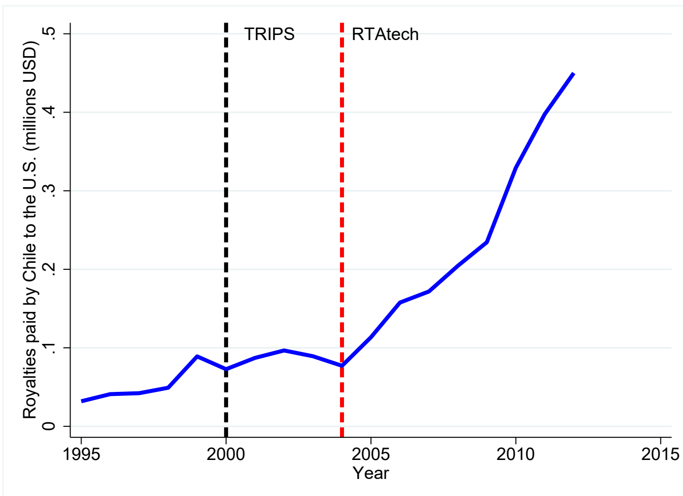
F International Licensing and RTAs with IP Provisions: Examples

Figure 7 shows the dynamics of royalty payments for a sample of country-pairs. There are two vertical lines: One refers to when TRIPS was ratified by the developing country, and the other refers to when the first RTA with technology provisions enter into enforcement.[15] 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.

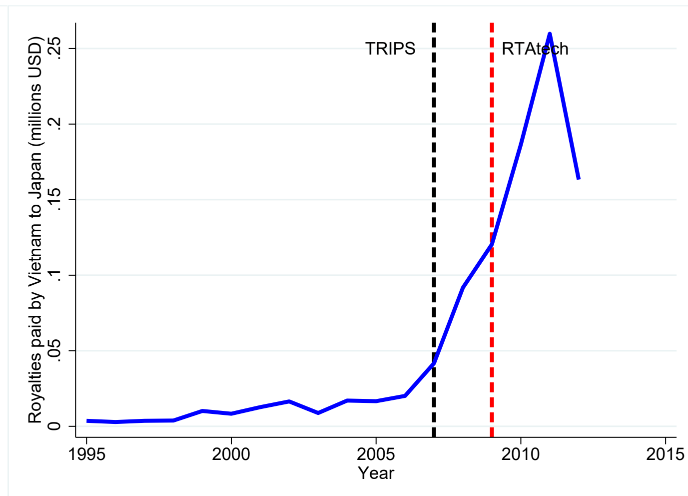
[15] Although TRIPS was established in 1995 as a requirement to be part of the WTO, many developing countries were granted an extension to meet the IP requirements, and in those countries the agreement was ratified after 1995.

Figure 7: Dynamics of International Technology Licensing During RTAs with IP Provisions

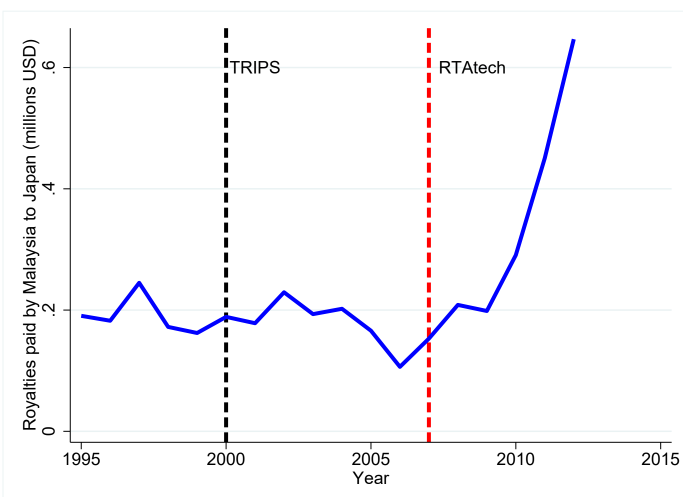
(a) USA to Chile



(b) Japan to Vietnam



(c) Japan to Malaysia



(d) Singapore to China