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Do Deep Regional Trade Agreements Facilitate International Research Collaboration?*

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Abstract

We examine whether regional trade agreements (RTAs) facilitate international research collaboration. First, using a two-country model of a continuum of oligopolitic industries with process research and development (R&D) investment and spillovers, we analyze whether trade liberalization through a trade agreement with deep economic integration increases the number of firms that engage in research collaboration. We then empirically investigate the effects of deep RTAs by employing data on patents with multiple inventors from different countries at the United States Patent and Trademark Office (USPTO) for 114 countries/regions over the period 1990–2011. We interpret co-inventions by inventors residing in different countries as evidence of international research collaboration. We use dummy variables and indexes to measure the extent of economic integration by RTAs. We find that deeper integration is associated with more active international co-inventions. We check the robustness of our findings by employing various specifications and addressing endogeneity issues.

Keywords: Research collaboration; international co-invention; regional trade agreement; deep integration.

JEL classification: L13; O31; O33; F15.

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1 Introduction

Inventive activities play an essential role in the production and product development of firms worldwide. Moreover, not only their own research but also international research collaboration among multinational firms and universities have critical value. In particular, the importance of the latter among multinational firms has recently become greater than ever. Several studies have investigated the determinants of international research collaboration (e.g., Hoekman et al., 2009, 2010; Montobbio and Sterzi, 2013; Picci, 2010; Tsukada and Nagaoka, 2015). However, previous studies have not fully analyzed the effects of economic integration by signing regional trade agreements (RTAs) on international research collaboration. This study attempts to fill this gap.

In the beginning, RTAs are primarily aimed at enhancing international trade in goods and services by reducing tariffs on imports reciprocally among signatories. However, many recent RTAs pursue "deeper" integration (Baldwin, 2011). For example, a number of RTAs now include provisions on the harmonization of intellectual property rights (IPR) protection and on research and technology. In particular, the European Union (EU) has implemented active science, innovation, and technology policies through Framework Programmes to foster collaborative research partnerships among European countries (Roediger-Schluga and Barber, 2008). Therefore, RTAs may facilitate international research collaborations among member countries.

An important issue in our study is how we can measure the "depth" of economic integration. In this respect, Horn et al. (2010) propose a framework to systematically measure the depth of RTAs. They define the content and legal enforceability of various provisions included in RTAs in two categories: WTO-plus (WTO+) and WTO-extra (WTO–X). 14 policy areas are classified within the WTO+ category and 38 policy areas are in the WTO–X category. Table 1 lists the WTO+ and WTO–X policy areas. The WTO–X category includes provisions particularly related to research collaborations, such as IPR, innovation policies, and research and technology, while the WTO+ category includes industrial products, agricultural products, and trade-related aspects of intellectual property rights (TRIPs), which are not directly related to research collaborations. Horn et al. (2010) also evaluate the extent to which each WTO+ and WTO–X provision is legally enforceable in RTAs, measured on a scale of zero to two.

(Insert Table 1).

In this study, we investigate whether WTO+ and WTO–X provisions in RTAs actually facilitate international collaboration in research activities among member countries. To capture the effect of WTO+ and WTO–X provisions on international research collaboration, we use two types of variables. The first type is a simple dummy variable that measures whether a country pair belongs to RTAs that include WTO+ or WTO–X provisions. The second type is the sum of the points of legally enforceable WTO+ or WTO–X provisions covered by RTAs to which a country pair belongs.

Another important issue is understanding the methodology of empirically measuring the scale (or magnitude) of international research collaboration. In this study, we use data on patents with multiple inventors residing in different countries. A number of previous studies have adopted the same approach (e.g., Cappelli and Montobbio, 2016; Hoekman et al., 2009; Montobbio and Sterzi, 2013; Tsukada and Nagaoka, 2015).

Our empirical framework is as follows. We employ the number of patents with multiple inventors per pair of countries as the dependent variable in our regressions. Our sample covers 114 countries/regions and 160 RTAs for the 12 years from 1990 to 2011. With regard to explanatory variables, we include dummy variables and indexes to reflect the coverage and extent of the legal enforceability of the WTO+ and WTO–X provisions in RTAs. The dummy variables capture the average effect of the common RTA membership that covers WTO+ or WTO–X provisions on international co-inventions, and the WTO+ and WTO–X indexes capture the impact of the degree of deep regional integration on international co-inventions.[1] We first estimate the empirical model for international research collaboration using ordinary least squares (OLS). Next, we estimate the model using a Poisson pseudo-maximum-likelihood (PPML) estimator, mainly because our dependent variable (i.e., the number of patents with multiple inventors) is count data and there are many zeros in the dependent variable. Moreover, to account for possible endogeneity in the WTO+ and WTO–X dummies and indexes, we employ the instrumental variable (IV) approach.

Before conducting the empirical analysis, we theoretically investigate whether trade liberalization through trade agreements with deep integration increases the number firms that engage in research

[1] Note that a formation of an RTA by itself does not necessarily facilitate patent applications among member countries in our data because we use data from the USPTO rather than from patent offices in individual countries. Thus, we do not need to worry about the possibility of such a "facilitation effect" being included in the WTO+ and WTO–X dummies and indexes.

collaboration. For this, we use a two-country model of a continuum of oligopolitic industries with a three-stage game in which firms invest in cost-reducing R&D and decide whether to collaborate on R&D. Firms may have an incentive to engage in research collaboration because of the existence of spillover effects in the outcome of R&D.

Our main findings are as follows. First, our theoretical analysis shows that when initial tariffs are symmetric, a mutual tariff reduction through trade agreements increases the number of firms that engage in research collaboration. However, the effect of deep trade agreement, which facilitates the exchange of knowledge and technology among firms in member countries, on research collaboration depends on the degree of knowledge spillovers. If the degree of knowledge spillovers is high, then a deep trade agreement increases the number of firms that engage in research collaboration more than a shallow trade agreement that only reduces tariffs. However, if the degree of knowledge spillovers is low, the opposite result holds. Consequently, our theoretical results need empirical analysis to elucidate the effect of deep trade agreements on international research collaboration. We find, by empirical analysis, that the estimated coefficients of the WTO+ and WTO–X dummies are positive and highly significant. This finding is quite robust for different estimation techniques. Moreover, we find that the depth of integration is positively associated with international co-invention. The estimated coefficients of the WTO+ and WTO–X indexes are both positive and highly significant, and the latter shows stronger effects on international co-invention. Finally, we show that our results do not qualitatively change even when we address the possible endogeneity issue by employing the IV estimator. Therefore, our empirical results imply that deep economic integration facilitates research collaboration among economic agents in member countries.

A number of previous studies are related to this study. First, there are many existing theoretical studies on R&D spillovers and research collaboration (e.g., d'Aspremont and Jacquemin, 1988; Kamien et al., 1992). Although the impact of R&D policies, such as R&D subsidy and tax, on firms' R&D investment and competition, and the design of the optimal R&D policies have been analyzed in the literature (e.g., Goel and Haruna, 2011; Haaland and Kind, 2008; Leahy and Neary, 1999; Qiu and Tao, 1998), none of the existing studies has investigated the effects of trade agreements on firms' incentive to engage in research collaboration. Two exceptions are Ghosh and Lim (2013) and Zu et al. (2011). Ghosh and Lim (2013) examine how a change in trade cost affects firms' R&D investment under non-cooperative and cooperative R&D and whether firms have an incentive to engage in research collaboration, given the level of trade cost. However, they do not investigate how the formation of a bilateral trade agreement affects firms' incentive to engage in research collaboration. On the other hand, Zu et al. (2011) analyze the relationship between the free trade agreement (FTA) networks and the research collaboration networks in the model of three symmetric countries and firms. The focus of their analysis is on the pairwise stability of research collaboration networks in the presence or absence of the FTA networks and the impact of forming bilateral FTAs on firms' R&D investment levels under different research collaboration networks. However, they do not examine whether the formation of a bilateral trade agreement increases or decreases firms' incentive to engage in research collaboration. Therefore, the effects of trade agreements on the firms' incentive are an remaining issue.

Second, there are a number of empirical studies on research collaboration. As mentioned above, Hoekman et al. (2009) analyze the effects of geographical and institutional distance on inter-regional research collaboration in Europe using the gravity equation. Hoekman et al. (2010) examine the changing effect of physical distance and territorial borders on the intensity of research collaboration across European regions. They find that the bias towards collaboration with physically proximate partners has not decreased, whereas the bias towards collaboration within territorial borders has decreased over time. Montobbio and Sterzi (2013) focus on technological collaboration between eleven emerging and seven advanced countries by employing the gravity model. They measure international technological collaboration based on the number of patents co-signed by at least one inventor resident in an emerging country and at least one inventor resident in an advanced country, finding that technological proximity and sharing a common language are key determinants of technological collaboration. This indicates that geographical distance and longitude are influential on collaboration for new technology creation. Using the information on patents at the European Patent Office (EPO), Picci (2010) finds that international research collaboration is positively affected by the presence of a common language, a common border, and by more similar cultural characteristics, and that it is negatively affected by geographical distance. Focusing on international research collaboration among the US, European countries, Japan, and three Asian countries (China, Korea, and Taiwan), Tsukada and Nagaoka (2015) analyze how changes in invention practices in the US, such as inventor team size and the number of references to scientific prior art, affect the likelihood that an international co-invention (ICI) is chosen in other countries. They find that ICIs are more prevalent in the technology sectors in which scientific literature is important as prior art, inventor team size enlarges, and the relative inventor resources of the country in the world decline. They also estimate a gravity model to investigate how the characteristics of the bilateral relationship and the trade and investment relationships affect ICIs between the US (or the UK) and partner countries and find that lower language barriers measured by the Test of English as a Foreign Language (TOEFL) scores are an important driving force behind ICIs between the US (or the UK) and partner countries. Recently, Iino et al. (2021) have analyzed the effect of the global network of research collaborations on the quality of innovation by using firm-level data on patents and patent citations of various patent offices, including the World Intellectual Property Organization (WIPO), the USPTO, the EPO, and the Japan Patent Office (JPO) with firm attributes. They show that research collaborations with other firms, particularly foreign firms, substantially improve the quality of innovation.

There is a growing body of literature on deep RTAs. For example, Horn et al. (2010) developed a methodology to create a database of WTO+ and WTO–X provisions in RTAs. Orefice and Rocha (2014) analyzed the impact of deep RTAs on production networks using the definitions of Horn et al. (2010). Hofmann et al. (2019) extend the coverage in the database of the content of RTAs. Using the database of Hofmann et al. (2019), Mattoo et al. (2017) analyze how deep integration affects the trade creation and trade diversion effects of RTAs. Dür et al. (2014) develop the original dataset of deep integration and show that RTAs increase trade flows and that such a positive effect is largely driven by deep integrations. Jinji et al. (2019) examine whether deep RTAs enhance international technology spillovers using patent citation data by measuring the depth of integration by the extent to which an RTA includes WTO–X provisions. They find that the depth of integration actually influences technology spillovers, and that deep integration in a broad sense has a greater impact on technology spillovers than technology-related provisions. However, they do not examine the effect of deep RTAs on international research collaboration.

The remainder of the study is organized as follows. In Section 2, we present the theoretical analysis. In Section 3, we explain the framework for empirical analysis. In Section 4, we describe the data employed in our empirical analysis and in Section 5, we present our empirical results. Finally, Section 6 concludes the study.

2 The Model

2.1 The basic setting

We consider a symmetric two-country model in which there is a continuum of oligopolitic industries and a numeraire industry. To simply the analysis, we assume the following additively separable quasi-linear utility function for the representative household in country i, $i = 1, 2$:

$$U[Q_i(\omega)] = Q_i^N + \int_0^1 u[Q_i(\omega)]d\omega, \tag{1}$$

where Q_i^N denotes consumption of the numeraire good and $Q_i(\omega)$ denotes consumption of the good produced in industry $\omega \in [0, 1]$. We further assume the quadratic function for the sub-utility $u[\cdot]$:

$$u[Q_i(\omega)] = aQ_i(\omega) - \frac{1}{2}b\{Q_i(\omega)\}^2, \qquad a > 0,\ b > 0, \tag{2}$$

which yields the following inverse demand for good ω in country i:

$$p_i(\omega) = \alpha - Q_i(\omega), \tag{3}$$

where $p_i(\omega)$ is the price of good ω in country i, $\alpha \equiv a/\lambda$, and we normalize as $b/\lambda = 1$ with λ being the Lagrange multiplier.

The numeraire industry in each country is perfectly competitive. On the other hand, for simplicity, we assume that in each oligopolistic industry one firm is located in each country. We label firms by the same numbers as the countries, i.e., $i = 1, 2$. The two firms in each oligopolistic industry produce homogeneous goods and supply them to markets in both countries.

Let $q_{hi}(\omega)$ and $q_{ei}(\omega)$ be the outputs of firm i in industry ω for the domestic and foreign markets (i.e., exports), respectively.[2] Thus, it holds that $Q_i(\omega) = q_{hi}(\omega) + q_{ej}(\omega)$, $i, j = 1, 2$, $i \neq j$. We assume constant returns to scale in all of the oligopolistic industries. The two firms in the same industry share the same initial marginal cost, but the oligopolistic industries are heterogeneous in their initial marginal costs.[3] Let $c(\omega)$ be the initial marginal cost of firms in industry ω, where $c(\omega)$ is distributed over the range of $c(\omega) \in [\underline{c}, \bar{c}]$, where $\underline{c} > 0$ holds. We order the industries so that $dc(\omega)/d\omega \geq 0$, $c(0) = \underline{c}$, and $c(1) = \bar{c}$ hold.

[2]See, for example, Goel and Haruna (2011) for the analysis of the relationship between R&D with spillovers and trade.

[3]This model setting is similar to that of the Ricardian model with a continuum of goods developed by Dornbusch et al. (1977).

Firms in each oligopolistic industry can invest in process R&D to reduce their initial marginal costs. Following d'Aspremont and Jacquemin (1988), we assume that firm i in industry ω can reduce its marginal cost by $x_i(\omega)$ by spending $\gamma\{x_i(\omega)\}^2/2$, where γ indicates the degree of efficiency of R&D investment.[4] Efficiency of R&D investment decreases as the value of γ rises. To ensure that the second-order conditions for profit maximization and the local stability conditions for equilibria in the second stage are satisfied in all cases that we consider, we assume that $\gamma > 4$ holds. The R&D investment of each firm is rewarded with outcomes such as patents on revisions to its manufacturing process and those on new production technology. However, the outcome of firm i's R&D investment in industry ω is not perfectly appropriated by itself. That is, it may spill over to its rival in the same industry (d'Aspremont and Jacquemin, 1988).[5] The degree of spillovers is measured by $\beta \in [0, 1]$, where $\beta = 0$ indicates no spillovers and $\beta = 1$ indicates perfect spillovers. Thus, firm i's marginal production cost after R&D investment is given by $c(\omega) - \{x_i(\omega) + \beta x_j(\omega)\}$, where $x_i(\omega) + \beta x_j(\omega)$ is taken as the effective cost reduction of R&D investments acquired by the firm i in industry ω.

As a result of the R&D spillovers, firms may have an incentive to cooperate over R&D investment (Kamien et al., 1992) — we call this "research collaboration."[6,7] When firms engage in research collaboration, they choose $x_1(\omega)$ and $x_2(\omega)$ to maximize their joint profits $\Pi(\omega) \equiv \pi_1(\omega) + \pi_2(\omega)$. In this case, each firm must pay a fixed cost f as coordination costs. On the other hand, when they choose the R&D investment non-cooperatively, firm i chooses $x_i(\omega)$ to maximize its own profits $\pi_i(\omega)$, given the rival's R&D investment, $x_j(\omega)$.[8]

We consider a three-stage game model for analysis. The structure of the game is as follows. In the

[4]Although $x_i(\omega)$ represents the outcome of R&D in terms of the reduction in marginal production cost, we also refer to $x_i(\omega)$ as "R&D investment" for expressional simplicity.

[5]To simplify the analysis, we assume that there are no cross-industry spillovers.

[6]This case corresponds to "R&D cartelization", not "RJV cartelization", in Kamien et al. (1992). The spillover rate in RJV cartelization increases to its maximum rate, that is, $\beta = 1$. Falvey and Teerasuwannajak (2016) analyze how the governments' R&D policies, such as R&D subsidies and taxes, and the coordination of the R&D policies affect firms' choice of the R&D alliance form from several possible forms, including R&D cartelization and RJV cartelization.

[7]In our model setting the presence of the R&D spillover is the primary reason for firms to engage in research collaboration. However, there could be another reason for this. For example, research subjects solved by a single firm are obviously limited in terms of research funds and professional human resources. One solution to these limitations is to organize research collaborations with other firms.

[8]In this study we do not consider the possibility of domestic research collaboration. As our main interest is the impact of deep RTAs on international research collaboration, we just focus on international research collaboration.

first stage, the two firms decide whether to engage in research collaboration. In the second stage, the firms choose the level of R&D investment. If both firms choose to engage in research collaboration in the first stage, they choose the level of R&D investment cooperatively. Otherwise, they choose the level of R&D investment non-cooperatively. Finally, in the third stage, the two firms compete in a Cournot fashion in both markets. The solution concept is the subgame perfect Nash equilibrium; hence, the model is solved by backward induction.

In the following analysis, we assume that, initially, a uniform tariff $t_i > 0$ is exogenously imposed on country i's imports of all oligopolistic goods $\omega \in [0, 1]$. We then examine how a reciprocal tariff reduction due to a trade agreement will affect the equilibrium outcome.

2.2 The third stage

For notational simplicity, we omit ω in the subsequent analysis unless omissions cause confusion.

First, we analyze the Cournot competition in the third stage. Firm i's profits are given by

$$\pi_i = p_i q_{hi} + p_j q_{ei} - [c - (x_i + \beta x_j)](q_{hi} + q_{ei}) - t_j q_{ei} - \frac{\gamma(x_i)^2}{2}. \tag{4}$$

The first-order conditions for profit maximization are given by

$$\frac{\partial \pi_i}{\partial q_{hi}} = 0, \qquad \frac{\partial \pi_i}{\partial q_{ei}} = 0, \qquad i = 1, 2. \tag{5}$$

It is easy to verify that the second-order conditions are satisfied, and hence, the two markets are locally stable under certain conditions on parameters.

Then, from the first-order conditions, the Nash equilibrium in the third stage is given by

$$q_{hi} = \frac{\alpha - c + t_i + (2 - \beta)x_i + (2\beta - 1)x_j}{3}, \qquad q_{ei} = \frac{\alpha - c - 2t_j + (2 - \beta)x_i + (2\beta - 1)x_j}{3}. \tag{6}$$

We assume $\alpha - \bar{c} - 2\max\{t_i,\ t_j\} > 0$ to guarantee an interior solution for all oligopolistic industries $\omega \in [0, 1]$.

Using the first-order conditions, the equilibrium profits of Eq. (4) can be expressed as

$$\pi_i = (q_{hi})^2 + (q_{ei})^2 - \frac{\gamma(x_i)^2}{2}. \tag{7}$$

2.3 The second stage: R&D competition case

Next, we analyze the second stage, in which firms decide the level of R&D investment. We first consider the case in which the firms choose R&D investment non-cooperatively.

The first-order condition of firm i $(i = 1, 2)$ for profit maximization is given by

$$\begin{aligned}\frac{d\pi_i}{dx_i} &= \frac{\partial \pi_i}{\partial q_{hi}}\frac{dq_{hi}}{dx_i} + \frac{\partial \pi_i}{\partial q_{hj}}\frac{dq_{hj}}{dx_i} + \frac{\partial \pi_i}{\partial q_{ei}}\frac{dq_{ei}}{dx_i} + \frac{\partial \pi_i}{\partial q_{ej}}\frac{dq_{ej}}{dx_i} + \frac{\partial \pi_i}{\partial x_i} \\ &= \frac{4-2\beta}{3}(q_{hi} + q_{ei}) - \gamma x_i \\ &= \frac{1}{9}\left[2(2-\beta)\{2(\alpha - c) + t_i - 2t_j\} + \{4(2-\beta)^2 - 9\gamma\}x_i + 4(2-\beta)(2\beta - 1)x_j\right] = 0, \quad (8)\end{aligned}$$

where $\partial\pi_i/\partial q_{hi} = 0$, $\partial\pi_i/\partial q_{ei} = 0$, $\partial\pi_i/\partial q_{hj} = -q_{ei}$, $\partial\pi_i/\partial q_{ej} = -q_{hi}$, and $dq_{hj}/dx_i = dq_{ej}/dx_i = (2\beta - 1)/3$.

The second-order conditions with respect to the R&D choices of the firms are satisfied. That is,

$$\frac{d^2\pi_i}{dx_i^2} = 4(2-\beta)^2 - 9\gamma < 0, \qquad i = 1, 2,$$

under $\gamma > 4$. Moreover, we assume that the equilibrium in the second stage is locally stable: $B^N < 0$ and $(B^N)^2 - (C^N)^2 > 0$, where $B^N = 4(2-\beta)^2 - 9\gamma$ and $C^N = 4(2-\beta)(2\beta - 1)$.

Solving the first-order conditions (8), we obtain the Nash equilibrium level of the non-cooperative R&D investment of firm i in the second stage as follows:

$$x_i^N = \frac{(4-2\beta)\left[2(\alpha - c)\{9\gamma - 12(2-\beta)(1-\beta)\} + (t_i - 2t_j)\{9\gamma - 4(2-\beta)^2\} + 4(t_j - 2t_i)(2-\beta)(2\beta - 1)\right]}{(B^N)^2 - (C^N)^2}, \quad (9)$$

where a superscript N indicates equilibrium variables under non-cooperative R&D investments.

It follows, from Eq. (9), that the effects of a tariff on R&D investment are given by

$$\begin{aligned}\frac{dx_i^N}{dt_i} &= \frac{6(2-\beta)[3\gamma - 4\beta(2-\beta)]}{(B^N)^2 - (C^N)^2} > 0, \\ \frac{dx_i^N}{dt_j} &= \frac{12(2-\beta)[-3\gamma + 2(2-\beta)]}{(B^N)^2 - (C^N)^2} < 0, \quad i, j = 1, 2, i \neq j.\end{aligned}$$

As a result of a rise in the tariff t_i, the marginal revenue of the firm i in the research competition increases, so that its R&D investment comes to an increase, whereas, as a result of a rise in the tariff t_j, its marginal revenue decreases, so that its R&D investment comes to a decrease. These results show that the rate of spillover affects the comparative static results to some extent, but not to great extent. The asymmetric responses of the firm are usual.

2.4 The second stage: R&D cooperation case

We next consider the case in which the firms choose R&D investment cooperatively.

In this case, the two firms choose their R&D investment levels to maximize their joint profits. Thus, the first-order conditions for joint profit maximization are given by

$$\begin{aligned}\frac{d\Pi}{dx_i} &= \frac{d\pi_i}{dx_i}+\frac{d\pi_j}{dx_i}\\ &= \frac{1}{9}\left[2(2-\beta)\{2(\alpha-c)+t_i-2t_j\}+2(2\beta-1)\{2(\alpha-c)+t_j-2t_i\}\right.\\ &\quad \left.+\{4(5-8\beta+5\beta^2)-9\gamma\}x_i+8(2-\beta)(2\beta-1)x_j\right]=0,\quad i,j=1,2,\ i\neq j. \qquad (10)\end{aligned}$$

The second-order conditions for joint profit maximization are satisfied under the assumption of $\gamma > 4$, i.e.,

$$\frac{d^2\Pi}{dx_i^2}=\frac{4(5-8\beta+5\beta^2)-9\gamma}{9}<0,\quad i=1,2.$$

From the first-order conditions (10) on both firms, we obtain the Nash equilibrium level of the cooperative R&D investment of firm i in the second stage:

$$\begin{aligned}x_i^C &= \frac{2}{(9\gamma-4(1+\beta)^2)(\gamma-4(1-\beta)^2)}\left[2(\alpha-c)(1+\beta)\{\gamma-4(1-\beta)^2\}-t_i\{4\beta(1-\beta^2)+\gamma(4-5\beta)\}\right.\\ &\quad \left.+t_j\{4(1-\beta^2)-\gamma(5-4\beta)\}\right],\quad i,j=1,2,\ i\neq j, \qquad (11)\end{aligned}$$

where a superscript C indicates equilibrium variables under cooperative R&D investments.

It follows, from Eq. (11), that the effects of a tariff on cooperative R&D investment are given by

$$\begin{aligned}\frac{dx_i^C}{dt_i} &= -\frac{2\{4\beta(1-\beta^2)+\gamma(4-5\beta)\}}{(9\gamma-4(1+\beta)^2)(\gamma-4(1-\beta)^2)},\\ \frac{dx_i^C}{dt_j} &= \frac{2\{4(1-\beta^2)-\gamma(5-4\beta)\}}{(9\gamma-4(1+\beta)^2)(\gamma-4(1-\beta)^2)}<0,\quad i,j=1,2,i\neq j.\end{aligned}$$

As for the first comparative static result we find out that the effect of the tariff t_i on the cooperative R&D investment x_i^C of the firm i depends crucially on the degree of the spillover rate. Namely, its effect gets negative, i.e., $(dx_i^C)/(dt_i) < 0$, at least for $0 \le \beta \le 4/5$, but positive, i.e., $(dx_i^C)/(dt_i) > 0$, in the neighborhood of $\beta = 1$. The reason for the former result is that the marginal revenue of cooperative R&D of the firm i becomes less than its marginal cost. The reason for the latter result is that its marginal revenue becomes larger than the marginal cost through large spillover rates when the tariff is raised. In contrast, the effect of the tariff t_j on the cooperative R&D investment of the firm i gets negative when its tariff is raised. That is, an increased tariff of the country j causes the cooperative R&D investment of the firm i to reduce, independent of the spillover rate. This result is the same as in the competitive R&D case.

2.5 The first stage: The decision of research collaboration

Given the analysis in the previous subsections, we examine whether the two firms have an incentive to engage in research collaboration in the first stage. We then compare the equilibrium profits in the cooperative and non-cooperative cases.

Let $\pi_i^N(\omega)$ and $\pi_i^C(\omega)$ be firm i's equilibrium profits in industry ω with and without research collaboration, respectively. Then, from Eq. (7), $\pi_i^N(\omega)$ and $\pi_i^C(\omega)$ are given by

$$\begin{aligned}\pi_i^N(\omega) &= \{q_{hi}^N(\omega)\}^2 + \{q_{ei}^N(\omega)\}^2 - \frac{\gamma\{x_i^N(\omega)\}^2}{2},\\ \pi_i^C(\omega) &= \{q_{hi}^C(\omega)\}^2 + \{q_{ei}^C(\omega)\}^2 - \frac{\gamma\{x_i^C(\omega)\}^2}{2} - f.\end{aligned}$$

Thus, the choice of research collaboration depends on the sign of

$$\pi_i^C(\omega) - \pi_i^N(\omega) = \{q_{hi}^C(\omega)\}^2 - \{q_{hi}^N(\omega)\}^2 + \{q_{ei}^C(\omega)\}^2 - \{q_{ei}^N(\omega)\}^2 - \frac{\gamma}{2}\left[\{x_i^C(\omega)\}^2 - \{x_i^N(\omega)\}^2\right] - f. \quad (12)$$

When $\pi_i^C(\omega) \geq \pi_i^N(\omega)$ holds, firm i chooses research collaboration. On the other hand, when $\pi_i^C(\omega) < \pi_i^N(\omega)$ holds, firm i chooses R&D competition.

In general, the right-hand side of Eq. (12) is a higher–order polynomial, and the sign depends on the parameter values.

We focus on the case of symmetric tariffs, that is, $t_1 = t_2 \equiv t$. It yields that $x_1^k(\omega) = x_2^k(\omega)$ for $k = N, C$. Moreover, from Eqs. (6), (9), and (11), we have

$$q_{hi}^C(\omega) - q_{hi}^N(\omega) = \frac{1+\beta}{3}\left\{x_i^C(\omega) - x_i^N(\omega)\right\}, \qquad q_{ei}^C(\omega) - q_{ei}^N(\omega) = \frac{1+\beta}{3}\left\{x_i^C(\omega) - x_i^N(\omega)\right\}, \quad i = 1, 2, \quad (13)$$

and

$$x_i^C(\omega) - x_i^N(\omega) = \frac{18\gamma(2\beta - 1)[2\{\alpha - c(\omega)\} - t]}{A^C A^N}, \quad (14)$$

where $A^C \equiv 9\gamma - 4(1+\beta)^2 > 0$ and $A^N \equiv 9\gamma - 4(1+\beta)(2-\beta) > 0$. It is straightforward to prove that $x_i^C(\omega) = x_i^N(\omega)$ holds if $\beta = 1/2$. Then, substituting Eqs. (13) and (14) into Eq. (12), we obtain

$$\pi_i^C(\omega) - \pi_i^N(\omega) = \frac{\gamma(2\beta - 1)[2\{\alpha - c(\omega)\} - t]\left\{x_i^C(\omega) - x_i^N(\omega)\right\}}{A^N} - f = \frac{18\gamma^2(2\beta - 1)^2[2\{\alpha - c(\omega)\} - t]^2}{A^C(A^N)^2} - f. \quad (15)$$

From Eq. (15), the following proposition is obtained:

Proposition 1 *Consider the case of symmetric tariffs. If coordination costs of research collaboration, f, are sufficiently high, (i) when $\beta = 1/2$, $\pi_i^C(\omega) < \pi_i^N(\omega)$ holds for all t, (ii) when $\beta \neq 1/2$, there* *is a threshold tariff level,* $\tilde{t}(\omega) > 0$*, such that* $\pi_i^C(\omega) = \pi_i^N(\omega)$ *holds. Then,* $\pi_i^C(\omega) \leq \pi_i^N(\omega)$ *holds for* $t \geq \tilde{t}(\omega)$ *and* $\pi_i^C(\omega) \geq \pi_i^N(\omega)$ *holds for* $t \leq \tilde{t}(\omega)$*.*

Proof. (i) When $\beta = 1/2$, it holds from Eq. (15) that $\pi_i^C(\omega) - \pi_i^N(\omega) = -f < 0$, regardless of the value of t.

(ii) When $\beta \neq 1/2$, from Eq. (15), $\tilde{t}(\omega)$ is implicitly defined as

$$\frac{18\gamma^2(2\beta-1)^2[2\{\alpha - c(\omega)\} - \tilde{t}(\omega)]^2}{A^C(A^N)^2} = f. \tag{16}$$

Then, it is straightforward to show that $\pi_i^C(\omega) \leq \pi_i^N(\omega)$ holds for $t \geq \tilde{t}(\omega)$ and $\pi_i^C(\omega) \geq \pi_i^N(\omega)$ holds for $t \leq \tilde{t}(\omega)$. ∎

This proposition shows that if the level of spillovers is $\beta = 1/2$, outputs are the same under non-cooperative and cooperative R&D investments. Consequently, firms have no incentive to engage in research collaboration as far as $\beta = 1/2$, regardless of the level of tariffs. On the other hand, for any level of spillovers other than $\beta = 1/2$, the firms choose to engage in research collaboration in equilibrium if the symmetric tariff level is lower than $\tilde{t}(\omega)$, but they do not choose research collaboration otherwise. In the latter case, since the impact of spillovers is stronger as the symmetric tariff level is lower, firms have a higher incentive to engage in research collaboration. Since $\beta = 1/2$ is a peculiar knife-edge case, in the subsequent analysis, we focus on the case except $\beta = 1/2$.

Now, suppose that the symmetric tariffs are set at some level t^0, i.e., $t = t^0$. Then, we obtain the following proposition:

Proposition 2 *Suppose that* $t = t^0$*. Then, there exists an industry* ω^0 *such that* $\tilde{t}(\omega^0) = t^0$*. Assume that* $\omega^0 \in (0, 1)$ *holds. Then, firms in all industries* $\omega \in [0, \omega^0]$ *engage in research collaboration, whereas firms in all industries* $\omega \in (\omega^0, 1]$ *do not engage in research collaboration.*

Proof. Totally differentiating Eq. (16) yields $d\tilde{t}(\omega)/d\omega = -2(dc(\omega)/d\omega) \leq 0$, because $dc(\omega)/d\omega \geq 0$. Since $\tilde{t}(\omega^0) = t^0$ holds for the industry ω^0, then $\tilde{t}(\omega) \geq t^0$ holds for $\omega \in [0, \omega^0]$ and $\tilde{t}(\omega) < t^0$ holds for $\omega \in (\omega^0, 1]$. Proposition 1 implies that $\pi_i^C(\omega) \geq \pi_i^N(\omega)$ holds in industries $\omega \in [0, \omega^0]$ and $\pi_i^C(\omega) < \pi_i^N(\omega)$ holds in industries $\omega \in (\omega^0, 1]$. ∎

As industries are heterogeneous in their initial marginal costs, given that tariffs are symmetric and uniform for all goods, firms choose to engage in research collaboration in low marginal cost industries but they have no incentive to do so in high marginal cost industries. This is explained as follows. Firms in low marginal cost industries invest more on R&D than those in high marginal cost industries. Therefore, the firms with low initial marginal costs can curtail more duplication of their R&D expenses by research collaboration than those with high initial marginal costs. Consequently, the former have a greater incentive to engage in research collaboration than the latter.

2.6 Trade agreements

Next, we analyze whether a trade agreement between the two countries increases or decreases the number of firms that engage in research collaboration. We distinguish between the two types of trade agreements. The first type is a "shallow" trade agreement in which only tariffs are reciprocally reduced. This is represented by a fall in t. The second type is a "deep" trade agreement in which the degree of spillovers as well as tariffs changes. As for the latter case, Jinji et al. (2019) provide evidence that deep RTAs facilitate international technology spillovers. Based on this result, we assume that the degree of spillovers, β, increases in deep trade agreements, compared with the case of shallow trade agreements. Thus, deep trade agreements are represented by a fall in t with an increase in β.

The impacts of shallow and deep trade agreements are shown in the following proposition:

Proposition 3 *(i) A shallow trade agreement increases the number of firms that engage in research collaboration. (ii) A deep trade agreement increases the number of firms that engage in research collaboration more (less) than a shallow trade agreement if* $\beta > (<)\ 1/2$.

Proof. (i) From the definition of ω^0, it is straightforward to show that $-d\omega^0/dt = 1/2c'(\omega) \geq 0$. That is, a marginal reduction in the symmetric tariffs from the initial level of $t = t^0$ increases the threshold industry ω^0.

(ii) Solve Eq. (16) for $\tilde{t}(\omega)$ and differentiate it with respect to β to obtain

$$\frac{\partial \tilde{t}(\omega)}{\partial \beta} = -\frac{(2f)^{1/2} D}{3\gamma (A^c)^{1/2} (2\beta - 1)^2} < 0 \qquad \text{for} \quad \beta \in [0, 1/2), \tag{17}$$

and

$$\frac{\partial \tilde{t}(\omega)}{\partial \beta} = \frac{(2f)^{1/2} D}{3\gamma (A^c)^{1/2} (2\beta - 1)^2} > 0 \qquad \text{for} \quad \beta \in (1/2, 1], \tag{18}$$

where $D \equiv 8(\beta+1)^2(4\beta^2 - 7\beta + 7) + 9\gamma(9\gamma - 4\beta^2 - 2\beta - 16) > 0$ because of $\gamma > 4$. An increase in β due to a deep trade agreement shifts $\tilde{t}(\omega)$ up and hence makes ω^0 larger for $\beta \in (1/2, 1]$ but shifts $\tilde{t}(\omega)$ down and hence makes ω^0 smaller for $\beta \in [0, 1/2)$. ∎

Therefore, a shallow trade agreement is expected to increase the number of research collaboration between firms in the partner countries of the trade agreement. On the other hand, a deep trade agreement, which facilitates the exchange of knowledge and technology among firms in partner countries, may or may not increase the number of research collaboration in the partner countries more than a shallow trade agreement does. The effect depends on the initial level of the degree of spillovers. If the initial degree of spillovers is high, then a deep trade agreement increases the number of research collaboration more than a shallow trade agreement does. We expect that this is more likely to be the case in the real world, but theoretically we cannot exclude the other case.

As shown above, theoretically the effect of deep integration on international research collaboration is not uniform. It depends on the degree of spillovers. There are two ways to elucidate the effect of deep integration: One way is to use numerical analysis and the other way to use empirical analysis. We choose the second way, because it is more meaningful to empirically examine the effect of deep integration on international research collaboration through data on patents and RTAs than the first numerical way.

3 Empirical Framework

Our primary concern is estimating the relationship between the membership of RTAs and research collaborations among RTA members. To investigate this issue, we estimate the following equation:

$$\begin{aligned} CA_{ijt} &= \exp\Big(\beta_0 + \beta_1 RTA\_Variable_{ij,t-1} + \gamma_1 \ln(P_{it}) + \gamma_2 \ln(P_{jt}) + \gamma_3 PROX_{ijt} \\ &\quad + \varphi_t + \eta_i + \lambda_j + \psi_{ij} + \mu_{it} + \nu_{jt}\Big) \times \epsilon_{ijt}, \end{aligned} \tag{19}$$

where CA_{ijt} is the number of patents applied jointly by inventors in country i and j in year t to the USPTO. $RTA\_Variable_{ij,t-1}$ is either a dummy variable or an index to capture the effect of WTO+ or WTO–X provisions in RTAs to which both countries i and j belong at $t-1$, where $RTA\_Variable_{ij,t-1} \in \{RTA\ dummy_{ij,t-1},\ WTO^{+}\ index_{ij,t-1},\ WTO^{X}\ index_{ij,t-1},\ IPR\_Prov\ index_{ij,t-1}\}$. The first term in the braces, $RTA\ dummy_{ij,t-1}$, is a dummy variable that takes the value one if both countries belong to a common RTA at $t-1$ and zero otherwise. The second and the third terms in the braces, $WTO^{+}\ index_{ij,t-1}$ and $WTO^{X}\ index_{ij,t-1}$, are indexes to measure the coverage and extent of the legal enforceability of the WTO+ and WTO–X provisions in RTAs, respectively. Finally, $IPR\_Prov\ index_{ij,t-1}$ is an index to reflect the degree of the legal enforceability of the IPR-related provisions in RTAs.

$WTO^{+}\ index_{ij,t-1}$ and $WTO^{X}\ index_{ij,t-1}$ are constructed in the following way. Let $\mathbb{Z}^k$ be a set of policy areas categorized as type $k = +, X$, where + and X indicate the WTO+ and WTO–X provisions, respectively, and then let $z \in \mathbb{Z}^k$ be a policy area included in $\mathbb{Z}^k$. Hofmann et al. (2019) construct $q^{AC}_{m,z}$ and $q^{LE}_{m,z}$ for RTA m and each policy area z according to the following coding rule:

$$q^{AC}_{m,z} = \begin{cases} 0, & \text{if policy area } z \text{ is not covered in RTA } m, \\ 1, & \text{if policy area } z \text{ is covered in RTA } m, \end{cases}$$

$$q^{LE}_{m,z} = \begin{cases} 0, & \text{if the legal language on area } z \text{ is imprecise and not committing in RTA } m, \\ 1, & \text{if the legal language on area } z \text{ is precise or committing but not enforceable in RTA } m, \\ 2, & \text{if policy area } z \text{ is legally enforceable in } m, \end{cases}$$

where superscript AC indicates "acknowledgment" and LE indicates "legal enforceability."[9] Given that these may be signatories of multiple RTAs at $t-1$, let $\mathbb{M}_{ij,t-1}$ be the set of RTAs for which countries i and j are signatories at t. Then, we construct $WTO^{k}\ index_{ij,t-1}$ as follows:

$$WTO^{k}\ index_{ij,t-1} = w^k \sum_{z \in \mathbb{Z}^k} WTO^{k}\ index_{ij,t-1}(z), \qquad k = +, X,$$

where $w^k = 1/42$ for $k = +$, $w^k = 1/114$ for $k = X$, and

$$WTO^{k}\ index_{ij,t-1}(z) = \max_{m \in \mathbb{M}_{ij,t-1}} q^{AC}_{m,z} + \max_{m \in \mathbb{M}_{ij,t-1}} q^{LE}_{m,z}.$$

Thus, it holds that $WTO^{k}\ index_{ij,t-1}(z) \in [0, 3]$ for each policy area z. Here, $WTO^{k}\ index_{ij,t-1}(z) = 0$ means that policy area z is not mentioned by RTAs for which countries i and j are signatories at $t-1$. The index $WTO^{k}\ index_{ij,t-1}(z)$ takes the value of one if policy area z is mentioned, but its legal language is imprecise. It takes the value of two if the legal language on area z is precise or committing but not enforceable in RTAs of which countries i and j are signatories at $t-1$. Finally, it takes the value of three if policy area z is legally enforceable in RTAs of which countries i and j are signatories at $t-1$. By multiplying $\sum_{z \in \mathbb{Z}^k} WTO^{k}\ index_{ij,t-1}(z)$ with w^k, it holds that $WTO^{k}\ index_{ij,t-1} \in [0, 1]$.

The construction of $IPR\_Prov\ index_{ij,t-1}$ is similar to that of $WTO^{+}\ index_{ij,t-1}$ and $WTO^{X}\ index_{ij,t-1}$. $IPR\_Prov\ index_{ij,t-1}$ reflects TRIPs and IPR provisions only as policy area z

[9] Note that $q^{AC}_{m,z} = 1$ and $q^{LE}_{m,z} = 0$ may hold at the same time. However, for $q^{LE}_{m,z}$ to take either the value of one or two, it must hold that $q^{AC}_{m,z} = 1$.

with $w^k = 1/6$. We pick TRIPs and IPR provisions because these are most directly related to the degree of IPR protection, which is relevant to research collaboration. Then, similar to $WTO^+ \ index_{ij,t-1}$ and $WTO^X \ index_{ij,t-1}$, it holds that $IPR\_Prov \ index_{ij,t-1} \in [0,1]$.

In Eq. (19), we include three control variables: $\ln(P_{it})$, $\ln(P_{jt})$, and $PROX_{ijt}$. Variables $\ln(P_{it})$ and $\ln(P_{jt})$ are the logarithm values of the patent applications for countries i and j, respectively, and $PROX_{ijt}$ is an index of the technological proximity between i and j, as measured by the patent classes based on the International Patent Classification (IPC) at the 4-digit level. Moreover, a constant term (i.e., β_0) and various fixed effects represented by φ_t, η_i, λ_j, ψ_{ij}, μ_{it}, and ν_{jt} are also included in the estimation of Eq. (19).[10] ϵ_{ijt} denotes the error term.

The index of technological proximity between two countries, $PROX_{ijt}$, is based on the work of Jaffe (1986). We assume that the "technological position" of country i (j) in research areas in year t can be characterized by the vector $\boldsymbol{F}_{it}$ ($\boldsymbol{F}_{jt}$). This is a vector of the shares of four-digit patent classes, according to the IPC, in all USPTO patent applications by country i (j) in year t. Then, the proximity of i and j in the technology space is represented as an uncentered correlation between $\boldsymbol{F}_{it}$ and $\boldsymbol{F}_{jt}$:

$$PROX_{ijt} = \frac{\boldsymbol{F}'_{it}\boldsymbol{F}_{jt}}{\sqrt{\boldsymbol{F}'_{it}\boldsymbol{F}_{it}}\sqrt{\boldsymbol{F}'_{jt}\boldsymbol{F}_{jt}}}.$$

Note that the value of $PROX_{ijt}$ is bounded between zero and one, and is closer to one if countries i and j are positioned in close proximity to each other.

In Eq. (19), the coefficient of the $RTA \ dummy$ measures the impact of RTAs on research collaboration under the assumption that all RTAs that include at least one WTO+ provision have the same effect on research collaboration. In addition, the coefficients of the $WTO^+ \ index$ and $WTO^X \ index$ capture the impact of deep integration in RTAs on research collaboration by taking into account the number and enforceability of WTO+ or WTO–X provisions covered by RTAs. Similarly, the coefficient of $IPR\_Prov \ index$ indicates the impact of deep RTAs in the policy area of IPR protection on research collaboration. We expect positive signs for the coefficients of $RTA \ dummy$, $WTO^+ \ index$, $WTO^X \ index$, and $IPR\_Prov \ index$.

[10] In one specification we include the year and country fixed effects, whereas we include time-varying country fixed effects and country-pair fixed effects in another specification. These fixed effects address the issue of the omitted variable bias. In addition, we use a number of variables related to the country-pair-specific characteristics between the two countries as our instrumental variables, as explained in Section 5.2.1.

With regard to the control variables, we expect the signs of the coefficients of both $\ln(P_{it})$ and $\ln(P_{jt})$ to be positive, where $\ln(P_{it})$ and $\ln(P_{jt})$ represent the country's research capability. Then, $PROX_{ijt}$ is also expected to have a positive coefficient because countries that share similar technology may have a greater chance at research collaboration.

We first estimate Eq. (19) using the OLS method. In the OLS estimations, we use the logarithm of the co-application of patents (i.e., $\ln(CA_{ijt})$) as the dependent variable. Since our dependent variable, CA_{ijt}, is count data and includes many zeros, the OLS estimates of the log-linearized model may be biased and inefficient. To address this issue, we estimate Eq. (19) using the Poisson pseudo-maximum likelihood (PPML) estimator, which is recommended by the gravity literature to deal with the issue of zero trade flows (Santos Silva and Tenreyro, 2006, 2011; Head and Mayer, 2014).

Moreover, we address the issue of endogeneity for $RTA\_Variable_{ijt}$ by employing the instrumental variable (IV) approach. We, particularly, employ a two-stage least squares estimation (IV/2SLS).

4 Description of the Data

This section describes the data in our empirical analysis. First, the data on patents with foreign co-inventors at the USPTO are taken from the Autumn 2016 edition of the Worldwide Patent Statistical (PATSTAT) database released by the EPO. The PATSTAT database provides information on the addresses of the inventors and owners (or assignees) of the patents. If the inventors are from two or more different national addresses for a common patent application, it implies that the inventive human resources of different nations are combined within one research collaboration. As indicated by Tsukada and Nagaoka (2015), although co-invention does not cover all possible forms of research collaboration, it covers an important part of the research collaboration involving the combination of significant resources. Research collaboration defined in these terms has become important in recent years (Organisation for Economic Co-operation and Development (OECD), 2009; Nagaoka et al., 2010). Our sample covers the period of 1990–2011.

We also use the data on patent applications that are taken from the PATSTAT database, where we extract the USPTO patent statistics. We use these data to construct patent applications for each sample country and $PROX$ for every country pair.

Next, we explain the sample. The sample includes countries/regions that have at least one patent application to the USPTO during the sample period. Our sample covers 114 countries/regions (listed in Table A.1). We then construct a panel of 5,833 pairs of countries/regions from 1990 to 2011.

We construct dummy variables for the membership of the 160 RTAs based on the information taken from the web page of the WTO.[11] All RTAs notified to the WTO that came into force by the end of 2011 and to which at least two countries/regions in our sample are signatories are included in our sample.[12] The list of RTAs covered in our sample is shown in Table A.2. Data on the contents of 279 RTAs are obtained from the Deep Trade Agreements databse 1.0 (horizontal depth) provided by the World Bank.[13] This dataset was originally constructed by Horn et al. (2010) and extended by Hofmann et al. (2019).

Moreover, we use bilateral gravity variables, as explained in Section 5.2.1. All of them are taken from the geographical database provided by the Centre d'Études Prospectives et d'Informations Internationales (CEPII). Bilateral trade data to construct an instrumental variable, explained in Section 5.2.1, are taken from the BACI dataset provided by CEPII.

Descriptive statistics and correlations of the variables are provided in Tables A.3 and A.4, respectively.

5 Empirical Results

5.1 Baseline estimations

In this section we report our estimation results. First, the OLS estimation results are presented in Table 2. Estimations with the country fixed effects and year dummies are reported in columns (1)–(4), whereas those with country-year and country-pair fixed effects are reported in columns (5)–(8). The estimated coefficients on $\ln(P_j)$ and $\ln(P_i)$ are both positive and significant, as expected. The index of technological proximity ($PROX$) has a positive and highly significant coefficient in all the regressions. Thus, we can conclude that countries holding similar technology engage in research collaboration more.

(Insert Table 2).

[11] http://rtais.wto.org/UI/PublicMaintainRTAHome.aspx

[12] The sample included free trade areas, customs unions, and economic integration agreements, but excluded partial scope agreements.

[13] https://datacatalog.worldbank.org/search/dataset/0039575

The estimated results concerning the impact of RTAs are as expected. The coefficient on the RTA *dummy* is positive and highly significant, even after controlling for country-year and country-pair fixed effects in the estimations. The depth of RTAs, measured by WTO^{+} *index* and WTO^{X} *index*, is positively associated with co-invention. The estimated coefficients on the WTO^{X} *index* tend to be larger than those on WTO^{+} *index* (see columns (3), (4), (7), and (8)), suggesting that the depth of RTAs in the WTO–X area may be more important for facilitating research collaboration than that in the WTO+ area. Interestingly, the estimated coefficient on the IPR_Prov *index* is smaller than that on WTO^{X} *index*, implying that deep RTAs in policy areas included in the WTO–X category in general have a stronger impact on research collaboration than those in IPR-related policy areas.

We report the estimation results from the PPML model in Table 3. Similar to Table 2, the estimated results with the country fixed effects and year dummies are reported in columns (1)–(4), whereas those with country-year and country-pair fixed effects are reported in columns (5)–(8). Table 3 shows that the results are qualitatively quite similar to those of the OLS estimation. The estimated coefficients on the WTO^{+} *dummy*, WTO^{+} *index*, WTO^{X} *index*, and IPR_Prov *index* remain positive and highly significant, and the WTO^{X} *index* has a larger coefficient than the other variables. Again, the coefficient on the IPR_Prov *index* is not particularly larger than those on the other variables, suggesting that IPR-related provisions alone do not have a stronger impact on research collaboration than other WTO+ and WTO–X provisions.

(Insert Table 3).

5.2 Robustness checks

In the previous subsection we found a positive and significant relationship between RTAs and international co-inventions. We check the robustness of our findings in two ways: The first robustness check addresses the endogeneity issue; and the second one uses different lag variables.

5.2.1 Estimations with instrumental variables

The first issue is possible endogeneity. Namely, RTA *dummy*, WTO^{+} *index*, WTO^{X} *index*, and IPR_Prov *index* that we use as explanatory variables in our estimations may be endogenous variables. Following the suggestion by Angrist and Pischke (2008, Chapter 4), we employ the two-stage least squares (IV/2SLS) estimator to address the issue of endogeneity. We use two sets of IVs. Our first IV is the contagion index, as proposed by Baldwin and Jaimovich (2012) in the context of the "domino effect" of RTAs. According to the domino theory of regionalism (Baldwin, 1995), the signing of an RTA by some countries motivates some other countries that are excluded from the RTA to sign new RTAs through the trade diversion effect. Baldwin and Jaimovich (2012) empirically confirmed the presence of the contagion effect in RTA formation. Their idea is that the contagion effect of country j's RTA membership on county i can be captured by the contagion index:

$$ContagRTA_{ijt} = \sum_{k \in \Omega_{jt}} \left(\frac{X_{ijt}}{X_{it}}\right) \left(\frac{X_{kjt}}{M_{jt}}\right) RTA_{jkt},$$

where X_{ijt} represents the bilateral exports of country i to country j, X_{it} is country i's total exports, M_{jt} is country j's total imports, Ω_{jt} is the set of countries with which country j has an RTA in year t, and RTA_{jkt} is a dummy variable that takes the value of one if there is an RTA between j and k at t, and zero otherwise. Thus, $ContagRTA_{ijt}$ indicates the sum of the RTAs signed by country j up to year t, weighted by the export share of country j in i's total exports and the import share of country k in j's total imports. $ContagRTA_{ijt}$ is likely to be correlated with the state of the RTA formation between countries i and j, but is unlikely to be correlated with research collaborations between i and j.

We also employ the second set of IVs, that is, *Comcol* and *Smctry*, to check the robustness of the estimated results with the first IV. As in Egger et al. (2011), the second set of IVs is related to the historical status of country pairs. *Comcol* is a dummy variable that is set to one if the two countries had a common colonizer in the past and zero otherwise. *Smctry* is a dummy variable that takes the value of one if one country is part of the other in the past, and zero otherwise.

In all specifications, we include country-year fixed effects, but not country-pair fixed effects.[14]

Table 4 reports the estimated results of the IV/2SLS estimations. In all cases the test statistics indicate that the IV/2SLS estimations are properly performed.

[14]When we include country-pair fixed effects, *Comcol* and *Smctry* cannot be used as IVs because they are perfectly collinear with fixed effects. $ContagRTA_{ijt}$ is still a valid IV, but we find that all estimation results with country-year and country-pair fixed effects using $ContagRTA_{ijt}$ as IV show that the endogeneity test of the endogenous regressor cannot reject the null hypothesis of the specified endogenous regressors being treated as exogenous. These results suggest that the endogeneity issue can be properly addressed by including country-pair fixed effects, as argued by Baier and Bergstrand (2007) and Yotov et al. (2016).

(Insert Table 4).

The estimated results in Table 4 indicate that $RTA\ dummy$, $WTO^{+}\ index$, $WTO^{X}\ index$, and $IPR\_Prov\ index$ are positively related to international co-invention, even after the endogeneity issue is addressed. The estimated coefficients are all positive and highly significant. Thus, our results suggest that both RTA and the depth of integration are important for international research collaboration. Moreover, consistent with the results in the baseline estimations, the estimated coefficient on the $WTO^{X}\ index$ tends to be larger than that on the other variables, suggesting that deep integration in policy areas included in the WTO–X category has the strongest impact on international research collaboration.

5.2.2 PPML estimations with two-year lagged variables

The second robustness check uses different lag variables. We use one-year lagged $RTA\_Variable_{ij}$ in our baseline estimations. As Hall et al. (1986) point out, there exists a complicated lag structure for the relationship between R&D activities and patenting. Thus, it may take more than one year from actual research collaboration activities to patent applications. Taking this point into account, a one-year lag may not be appropriate to capture the lag in the impact of RTAs on patent applications by multiple inventors. To address this issue, we use two-year lagged $RTA\_Variable_{ij}$. The results of the PPML estimations with two-year lagged $RTA\_Variable_{ij}$ are reported in Table 5. Comparing the results in Table 5 with those in Table 3, we find that the results remain qualitatively the same, except for column (8), where the estimated coefficient on $IPR\_Prov\ index$ is still positive but becomes insignificant.[15]

(Insert Table 5).

6 Conclusions

In this study we examined from both empirical and theoretical viewpoints whether deep RTAs facilitate research collaborations among firms in member countries of RTAs. First, we developed a two-country model of a continuum of oligopolitic industries with process R&D and spillovers and analyzed whether

[15] Although we only report the results of PPML estimations, those of OLS remain the same by using two-year lagged $RTA\_Variable_{ij}$.

trade liberalization through a trade agreement with deep economic integration increases the number of firms that engage in research collaborations. We found that when initial tariffs are symmetric, a mutual tariff reduction through a trade agreement increases the number of firms that engage in research collaborations. However, the effect of deep trade agreements on research collaborations depends on the degree of knowledge spillover. If the degree of knowledge spillovers is sufficiently high, a deep trade agreement increases the number of firms that engage in research collaboration more than a shallow trade agreement does. We conducted an empirical analysis of the effects of deep RTAs on international research collaborations in order to investigate that effect clear. We then employed data on patents with multiple inventors from different countries at the USPTO for 114 countries/regions for the period 1990–2011. We found that the depth of integration is positively associated with international co-invention. The estimated coefficients of the WTO+ and WTO–X indexes are both positive and highly significant, and the latter shows a stronger effect on international co-invention. Moreover, we showed that the estimates of the WTO+ and WTO–X dummies and the WTO+ and WTO–X indexes generally become larger after employing the IV estimations, indicating that the endogeneity problem causes a downward bias. In summary, this study showed that deep economic integration facilitates research collaboration among economic agents in member countries.

From a trade policy perspective, it is worth positively concluding RTAs, especially deep RTAs, with other developed countries. International research collaboration will be promoted more among multinational firms with high productivity in partner countries by their conclusion. As a result, they are rewarded through cost reductions through spillovers among them, becoming competitive in the market. It follows from this that the promotion of international research collaboration is beneficial not only for relevant firms, but also for their countries. In particular, the value-added of deep RTAs will rise with increased research collaboration. An increase in such research collaboration will cut a path to RJV cartelization of firms. Consequently, the organization of a research collaboration produces a larger effect above the mere conclusion of RTAs as trade policy.

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Table 1: List of WTO+ and WTO–X Areas in RTAs

WTO+ Areas	WTO–X Areas	
FTA Industrial Goods	Anti-Corruption	Health
FTA Agricultural Goods	Competition Policy	Human Rights
Customs Administration	Environmental Laws	Illegal Immigration
Export Taxes	IPR	Illicit Drugs
SPS	Investment	Industrial Cooperation
TBT	Labor Market Regulation	Information Society
State Trading Enterprises	Movement of Capital	Mining
Anti-dumping	Consumer Protection	Money Laundering
Countervailing Measures	Data Protection	Nuclear Safety
State Aid	Agriculture	Political Dialogue
Public Procurement	Approximation of Legislation	Public Administration
TRIMs	Audio Visual	Regional Cooperation
GATS	Civil Protection	Research and Technology
TRIPs	Innovation Policies	SME
	Cultural Cooperation	Social Matters
	Economic Policy Dialogue	Statistics
	Education and Training	Taxation
	Energy	Terrorism
	Financial Assistance	Visa and Asylum

Source: Horn et al. (2010).

Table 2: Baseline Estimations: The Impacts of RTA on International Co-Inventions

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS
$RTA\ dummy_{ij,t-1}$	0.540***				0.102*			
	(0.062)				(0.058)			
$WTO^{+}\ index_{ij,t-1}$		0.623***				0.176**		
		(0.073)				(0.069)		
$WTO^{X}\ index_{ij,t-1}$			0.969***				0.394***	
			(0.115)				(0.120)	
$IPR\_Prov\ index_{ij,t-1}$				0.472***				0.174***
				(0.070)				(0.061)
$\ln(P_{it})$	0.421***	0.427***	0.433***	0.440***				
	(0.046)	(0.045)	(0.045)	(0.046)				
$\ln(P_{jt})$	0.204***	0.205***	0.206***	0.210***				
	(0.042)	(0.042)	(0.042)	(0.042)				
$PROX_{ijt}$	1.823***	1.868***	1.903***	1.950***	1.013***	1.014***	1.017***	1.007***
	(0.134)	(0.137)	(0.139)	(0.139)	(0.150)	(0.150)	(0.150)	(0.150)
Year FE	Yes	Yes	Yes	Yes				
Country FE	Yes	Yes	Yes	Yes				
Country-year FE					Yes	Yes	Yes	Yes
Country-pair FE					Yes	Yes	Yes	Yes
R^2	0.712	0.711	0.710	0.707	0.936	0.936	0.936	0.936
No. of obs.	13,638	13,638	13,638	13,638	12,191	12,191	12,191	12,191

Notes: (a) The dependent variable is $\ln(CA_{ijt})$. (b) "***", "**", and "*"denote 1%, 5%, and 10% significance levels, respectively. (c) Standard errors clustered by country pairs are in parentheses. (d) The regressions include the constant term.

Table 3: PPML Estimations: The Impacts of RTA on International Co-Inventions

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML	(6) PPML	(7) PPML	(8) PPML
$RTA\ dummy_{ij,t-1}$	0.647***				0.090*			
	(0.091)				(0.048)			
$WTO^{+}\ index_{ij,t-1}$		0.653***				0.152***		
		(0.094)				(0.050)		
$WTO^{X}\ index_{ij,t-1}$			1.402***				0.305***	
			(0.172)				(0.108)	
$IPR\_Prov\ index_{ij,t-1}$				0.588***				0.089*
				(0.079)				(0.054)
$\ln(P_{it})$	0.724***	0.730***	0.748***	0.750***				
	(0.057)	(0.055)	(0.050)	(0.055)				
$\ln(P_{jt})$	0.813***	0.818***	0.791***	0.755***				
	(0.057)	(0.057)	(0.057)	(0.055)				
$PROX_{ijt}$	2.315***	2.393***	2.402***	2.484***	1.329***	1.329***	1.312***	1.317***
	(0.238)	(0.248)	(0.243)	(0.259)	(0.219)	(0.219)	(0.221)	(0.221)
Year FE	Yes	Yes	Yes	Yes				
Country FE	Yes	Yes	Yes	Yes				
Country-year FE					Yes	Yes	Yes	Yes
Country-pair FE					Yes	Yes	Yes	Yes
Log likelihood	−88011.73	−88954.34	−88452.38	−90661.43	−39870.78	−39849.08	−39856.24	−39865.22
No. of obs.	126,762	126,762	126,762	126,762	127,748	127,748	127,748	127,748

Notes: (a) The dependent variable is CA_{ijt}. (b) Estimations are implemented using the Stata command `ppml` for (1)–(4) and `ppmlhdfe` for (5)–(8). (c) "***", "**", and "*" denote 1%, 5%, and 10% significance levels, respectively. (d) Standard errors clustered by country-pair are in parentheses. (e) Regressions include a constant term.

Table 4: IV/2SLS Estimates for Endogenous WTO+ & WTO–X

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$RTA\ dummy_{ij,t-1}$	2.187***				5.624***			
	(0.402)				(1.127)			
$WTO^{+}\ index_{ij,t-1}$		2.346***				6.731***		
		(0.426)				(1.364)		
$WTO^{X}\ index_{ij,t-1}$			4.390***				11.333***	
			(0.761)				(2.188)	
$IPR\_Prov\ index_{ij,t-1}$				2.857***				8.738***
				(0.555)				(2.279)
$PROX_{ijt}$	2.217***	2.578***	2.583***	2.686***	0.192	0.845	1.125*	0.999
	(0.337)	(0.286)	(0.280)	(0.294)	(0.825)	(0.731)	(0.636)	(0.850)
Country-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-pair FE	No	No	No	No	No	No	No	No
Endogeneity Test								
Chi-sq [p-value]	18.09[0.00]	17.11[0.00]	18.68[0.00]	21.24[0.00]	28.38[0.00]	26.23[0.00]	21.78[0.00]	23.89[0.00]
Underidentification test								
Kleibergen-Paap rk LM stat [p-value]	64.16[0.00]	60.05[0.00]	83.71[0.00]	50.10[0.00]	10.32[0.006]	11.15[0.004]	16.70[0.0002]	8.41[0.015]
Weak-instrument-robust inference								
Anderson-Rubin Wald test								
F stat [p-value]	25.27[0.00]	25.27[0.00]	25.27[0.00]	25.27[0.00]	27.04[0.00]	27.04[0.00]	27.04[0.00]	27.04[0.00]
Overidentification test								
Hansen J stat [p-value]					0.003[0.960]	0.000[0.985]	2.259[0.133]	0.339[0.915]
F test of excluded instruments								
F-value [p-value]	46.28[0.00]	47.09[0.00]	59.60[0.00]	39.55[0.00]	7.78[0.0004]	8.78[0.0002]	13.55[0.00]	6.11[0.002]
No. of obs.	1,2721	1,2721	1,2721	1,2721	1,2721	1,2721	1,2721	1,2721

Notes: (a) The dependent variable is $\ln(CA_{ijt})$. (b) Estimations are implemented using the Stata command `ivreghdfe`. (c) $ContagRTA$ is used in (1)–(4) and *Comcol* and *Smctry* are used in (5)–(8) as IVs. (d) "***", "**", and "*"denote 1%, 5%, and 10% significance levels, respectively. (e) Standard errors clustered by country-pair are in parentheses. (f) All regressions include a constant term.

Table 5: Robustness Check: PPML Estimations with Two-year Lagged Variables

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML	(6) PPML	(7) PPML	(8) PPML
$RTA\ dummy_{ij,t-2}$	0.647***				0.101**			
	(0.090)				(0.045)			
$WTO^{+}\ index_{ij,t-2}$		0.655***				0.156***		
		(0.093)				(0.047)		
$WTO^{X}\ index_{ij,t-2}$			1.380***				0.278***	
			(0.168)				(0.093)	
$IPR\_Prov\ index_{ij,t-1}$				0.582***				0.069
				(0.077)				(0.045)
$\ln(P_{it})$	0.727***	0.733***	0.751***	0.757***				
	(0.057)	(0.055)	(0.050)	(0.056)				
$\ln(P_{jt})$	0.811***	0.814***	0.790***	0.778***				
	(0.055)	(0.056)	(0.057)	(0.055)				
$PROX_{ijt}$	2.329***	2.417***	2.442***	2.531***	1.328***	1.324***	1.308***	1.310***
	(0.239)	(0.247)	(0.243)	(0.258)	(0.219)	(0.219)	(0.221)	(0.222)
Year FE	Yes	Yes	Yes	Yes				
Country FE	Yes	Yes	Yes	Yes				
Country-year FE					Yes	Yes	Yes	Yes
Country-pair FE					Yes	Yes	Yes	Yes
Log likelihood	−88051.42	−88945.28	−88698.15	−91007.92	−39865.48	−39843.59	−39856.34	−39872.29
No. of obs.	126,762	126,762	126,762	126,762	127,748	127,748	127,748	127,748

Notes: (a) The dependent variable is CA_{ijt}. (b) Estimations are implemented using the Stata command `ppml` for (1)–(4) and `ppmlhdfe` for (5)–(8). (c) "***", "**", and "*" denote 1%, 5%, and 10% significance levels, respectively. (d) Standard errors clustered by country-pair are in parentheses. (e) Regressions include a constant term.

Table A.1: Sampled Countries/Regions

No.	Country/Region	No.	Country/Region	No.	Country/Region
1	ALBANIA	39	GUATEMALA	77	NIGERIA
2	ALGERIA	40	GUINEA	78	NORWAY
3	ANGOLA	41	HONDURAS	79	OMAN
4	ARGENTINA	42	HONG KONG	80	PAKISTAN
5	ARMENIA	43	HUNGARY	81	PARAGUAY
6	AUSTRALIA	44	ICELAND	82	PERU
7	AUSTRIA	45	INDIA	83	PHILIPPINES
8	AZERBAIJAN	46	INDONESIA	84	POLAND
9	BAHRAIN	47	IRAQ	85	PORTUGAL
10	BANGLADESH	48	IRELAND	86	QATAR
11	BELARUS	49	ISRAEL	87	ROMANIA
12	BELGIUM	50	ITALY	88	RUSSIA
13	BOLIVIA	51	JAPAN	89	SAUDI ARABIA
14	BRAZIL	52	JORDAN	90	SENEGAL
15	BULGARIA	53	KAZAKHSTAN	91	SIERRA LEONE
16	CAMBODIA	54	KENYA	92	SINGAPORE
17	CANADA	55	KOREA	93	SLOVAK REPUBLIC
18	CHILE	56	KUWAIT	94	SLOVENIA
19	CHINA	57	LAO PEOPLE'S DEM. REP.	95	SOUTH AFRICA
20	COLOMBIA	58	LATVIA	96	SPAIN
21	COSTA RICA	59	LEBANON	97	SRI LANKA
22	CROATIA	60	LIBERIA	98	SWEDEN
23	CYPRUS	61	LIBYA	99	SWITZERLAND
24	CZECH REPUBLIC	62	LITHUANIA	100	SYRIA
25	DENMARK	63	MACEDONIA	101	TANZANIA
26	DOMINICAN REP.	64	MADAGASCAR	102	THAILAND
27	ECUADOR	65	MALAYSIA	103	TUNISIA
28	EGYPT	66	MALI	104	TURKEY
29	EL SALVADOR	67	MALTA	105	UGANDA
30	ESTONIA	68	MAURITIUS	106	UKRAINE
31	ETHIOPIA	69	MEXICO	107	UNITED KINGDOM
32	FINLAND	70	MOLDVA	108	UNITED STATES
33	FRANCE	71	MOROCCO	109	URUGUAY
34	GAMBIA	72	NEPAL	110	UZBEKISTAN
35	GEORGIA	73	NETHERLANDS	111	VENEZUELA
36	GERMANY	74	NEW ZEALAND	112	VIETNAM
37	GHANA	75	NICARAGUA	113	YEMEN REPUBLIC OF
38	GREECE	76	NIGER	114	ZIMBABWE

Table A.2: List of RTAs

RTA Name	RTA Type
Agadir Agreement	FTA
ASEAN Free Trade Area (AFTA)	FTA
ASEAN - Australia - New Zealand	FTA&EIA
ASEAN - India	FTA&EIA
ASEAN - Japan	FTA
ASEAN - Korea, Republic of	FTA&EIA
Armenia - Kazakhsta	FTA
Armenia - Moldova	FTA
Armenia - Russia	FTA
Armenia - Ukraine	FTA
Australia - Chile	FTA&EIA
Australia - New Zealand (ANZCERTA)	FTA&EIA
Central American Common Market (CACM)	CU
Canada - Chile	FTA&EIA
Canada - Colombia	FTA&EIA
Canada - Costa Rica	FTA
Canada - Israel	FTA
Canada - Peru	FTA&EIA
Andean Community (CAN)	CU
Caribbean Community and Common Market (CARICOM)	CU&EIA
Central European Free Trade Agreement (CEFTA) 2006	FTA
Economic and Monetary Community of Central Africa (CEMAC)	CU
Common Economic Zone (CEZ)	FTA
Commonwealth of Independent States (CIS)	FTA
Chile - China	FTA&EIA
Chile - Colombia	FTA&EIA
Chile - Costa Rica	FTA&EIA
Chile - Guatemala	FTA&EIA
Chile - Honduras	FTA&EIA
Chile - Japan	FTA&EIA
Chile - Mexico	FTA&EIA
Chile - El Salvador	FTA&EIA
China - Costa Rica	FTA&EIA
China - Hong Kong China	FTA&EIA
China - New Zealand	FTA&EIA
China - Singapore	FTA&EIA
Common Market for Eastern and Southern Africa (COMESA)	CU
Colombia - Mexico	FTA&EIA
Colombia - Northern Triangle	FTA&EIA
Costa Rica - Mexico	FTA&EIA
Dominican Republic - Central America - US FTA (CAFTA-DR)	FTA&EIA
East African Community (EAC)	CU
Eurasian Economic Community (EAEC)	CU
EC Treaty	CU&EIA
EC(12) Enlargement	CU
EC(15) Enlargement	CU&EIA
EC(25) Enlargement	CU&EIA
EC(27) Enlargement	CU&EIA
Economic Community of West African States (ECOWAS)	CU

RTA Name	RTA Type
European Economic Area (EEA)	EIA
European Free Trade Association (EFTA)	FTA&EIA
EFTA - Albania	FTA
EFTA - Canada	FTA
EFTA - Chile	FTA&EIA
EFTA - Colombia	FTA&EIA
EFTA - Croatia	FTA
EFTA - Egypt	FTA
EFTA - Israel	FTA
EFTA - Jordan	FTA
EFTA - Korea, Republic of	FTA&EIA
EFTA - Lebanon	FTA
EFTA - Morocco	FTA
EFTA - Mexico	FTA&EIA
EFTA - Peru	FTA
EFTA - SACU	FTA
EFTA - Singapore	FTA&EIA
EFTA - Former Yugoslav Republic of Macedonia	FTA
EFTA - Tunisia	FTA
EFTA - Turkey	FTA
Egypt - Turkey	FTA
EU - Albania	FTA&EIA
EU - CARIFORUM States EPA	FTA&EIA
EU - Chile	FTA
EU - Croatia	FTA
EU - Algeria	FTA
EU - Egypt	FTA
EU - Israel	FTA
EU - Iceland	FTA
EU - Jordan	FTA
EU - Korea, Republic of	FTA&EIA
EU - Lebanon	FTA
EU - Morocco	FTA
EU - Former Yugoslav Republic of Macedonia	FTA&EIA
EU - Mexico	FTA&EIA
EU - Norway	FTA
EU - Switzerland - Liechtenstein	FTA
EU - Tunisia	FTA
EU - Turkey	CU
EU - South Africa	FTA
Gulf Cooperation Council (GCC)	CU
Georgia - Armenia	FTA
Georgia - Kazakhstan	FTA
Georgia - Russian Federation	FTA
Georgia - Ukraine	FTA
Hong Kong - New Zealand	FTA&EIA
Israel - Mexico	FTA
India - Japan	FTA&EIA
India - Malaysia	FTA&EIA
India - Singapore	FTA&EIA
India - Sri Lanka	FTA
Jordan - Singapore	FTA&EIA
Japan - Indonesia	FTA&EIA
Japan - Mexico	FTA&EIA
Japan - Malaysia	FTA&EIA
Japan - Philippines	FTA&EIA
Japan - Singapore	FTA&EIA
Japan - Switzerland	FTA&EIA
Japan - Thailand	FTA&EIA
Japan - Viet Nam	FTA&EIA
Korea, Republic of - Chile	FTA&EIA

RTA Name	RTA Type
Korea, Republic of - India	FTA&EIA
Korea Republic of - Singapore	FTA&EIA
Southern Common Market (MERCOSUR)	CU&EIA
Mexico - Guatemala	FTA&EIA
Mexico - Nicaragua	FTA&EIA
Mexico - El Salvador	FTA&EIA
North American Free Trade Agreement (NAFTA)	FTA&EIA
New Zealand - Malaysia	FTA&EIA
New Zealand - Singapore	FTA&EIA
Pakistan - Malaysia	FTA&EIA
Pan-Arab Free Trade Area (PAFTA)	FTA
Pacific Island Countries Trade Agreement (PICTA)	FTA
Pakistan - China	FTA&EIA
Pakistan - Sri Lanka	FTA
Peru - Chile	FTA&EIA
Peru - China	FTA&EIA
Peru - Korea, Republic of	FTA&EIA
Peru - Singapore	FTA&EIA
Southern African Development Community (SADC)	FTA
South Asian Free Trade Agreement (SAFTA)	FTA
Singapore - Australia	FTA&EIA
Thailand - Australia	FTA&EIA
Thailand - New Zealand	FTA&EIA
Trans-Pacific Strategic Economic Partnership	FTA&EIA
Turkey - Albania	FTA
Turkey - Chile	FTA
Turkey - Croatia	FTA
Turkey - Georgia	FTA
Turkey - Israel	FTA
Turkey - Jordan	FTA
Turkey - Morocco	FTA
Turkey - Syria	FTA
Turkey - Former Yugoslav Republic of Macedonia	FTA
Turkey - Tunisia	FTA
Ukraine - Belarus	FTA
Ukraine - Kazakhstan	FTA
Ukraine - Moldova	FTA
Ukraine - Former Yugoslav Republic of Macedonia	FTA
Ukraine - Russia	FTA
Ukraine - Uzbekistan	FTA
US - Australia	FTA&EIA
US - Bahrain	FTA&EIA
US - Chile	FTA&EIA
US - Israel	FTA
US - Jordan	FTA&EIA
US - Morocco	FTA&EIA
US - Oman	FTA&EIA
US - Peru	FTA&EIA
US - Singapore	FTA&EIA
West African Economic and Monetary Union (WAEMU)	CU

Source: The web page of the WTO. http://rtais.wto.org/UI/PublicMaintainRTAHome.aspx

Notes: (1) The listed RTAs are all RTAs notified to WTO that entered into force by 2011 and of which at least two countries/regions in our sample are signatories are included in the sample. (2) RTA types are free trade agreements (FTA), customs unions (CU), and economic integration agreements (EIA).

Table A.3: Descriptive Statistics

Variable	No. of Obs.	Mean	Std. Dev.	Min	Max
CA	127,796	5.06	82.94	0.0	4963.00
P_1	127,796	1649.4	7329.0	0.0	178081.00
P_2	127,796	3153.6	18288.6	0.0	178081.00
$PROX$	127,796	0.20	0.248	0.00	1.00
$RTA\ dummy$	127,796	0.10	0.302	0.00	1.00
$WTO^{+}\ index$	127,796	0.070	0.227	0.00	0.976
$WTO^{X}\ index$	127,796	0.032	0.126	0.00	0.816
$IPR\_Prov\ index$	127,796	0.058	0.224	0.00	1.00
$ContagRTA$	127,796	0.003	0.014	0.00	0.684
$Comcol$	127,796	0.062	0.242	0.00	1.00
$Smctry$	127,796	0.011	0.102	0.00	1.00

Table A.4: Correlations of the Variables

	CA	P_1	P_2	$PROX$	RTA $dummy$	WTO^+ $index$	WTO^X $index$	IPR_Prov $index$	$ContagRTA$	$Comcol$	$Smctry$
CA	1.0000										
P_1	0.0916	1.0000									
P_2	0.3316	−0.0058	1.0000								
$PROX$	0.1509	0.1281	0.1458	1.0000							
RTA $dummy$	0.0448	0.0220	−0.0120	0.2837	1.0000						
WTO^+ $index$	0.0608	0.0375	−0.0002	0.3502	0.9190	1.0000					
WTO^X $index$	0.0549	0.0422	−0.0124	0.3588	0.7536	0.8953	1.0000				
IPR_Prov $index$	0.0576	0.0456	0.0101	0.3618	0.7746	0.8990	0.8327	1.0000			
$ContagRTA$	0.1706	−0.0067	0.3445	0.1722	0.1595	0.1920	0.1924	0.1678	1.0000		
$Comcol$	−0.0152	−0.0513	−0.0428	−0.0958	0.0267	0.0024	−0.0350	−0.0514	−0.0252	1.0000	
$Smctry$	0.0000	−0.0197	−0.0163	0.0039	0.1614	0.1132	0.0755	0.0503	0.0197	0.1130	1.000