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The impact of digital trade rules on firms' international joint patent applications

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ABSTRACT

International joint patent applications, a means of legal protection for co-developed technologies by firms from different countries, are being affected by the emerging digital trade rules. We use data on firms' joint patent applications with foreign partners from the Bureau van Dijk Orbis Intellectual Property database to investigate the impact of digital trade rules on international joint patent applications at the firm level. Our empirical result suggests that digital trade rules included within preferential trade agreements significantly promote local firms' international joint patent applications. This result holds after a series of endogeneity tests and robustness checks. In addition, we find that the promotion effect is heterogeneous across the types of provisions, the digital intensity of sectors, the geographical contiguity between countries and the types of collaboration entities. Moreover, we demonstrate that digital trade rules promote firms' international joint patent applications through a critical mechanism that digital regulatory differences between countries are reduced. Furthermore, we find that digital trade rules increase the breadth, depth, and quality of firms' international joint patent applications. Overall, our study enriches the understanding of the effects of digital trade rules and sheds light on the factors that influence firms' international joint patent applications.

1. Introduction

International joint patent applications, i.e., patent applications jointly filed by firms from different countries help collaborating parties to appropriate the value from their cross-border research and development (R&D) collaboration outcomes. According to the resource-based view, a core motivation for firms to engage in cross-border R&D collaboration is to acquire external complementary knowledge in order to jointly develop new technologies (Arranz and de Arroyabe, 2008; Choi and Beamish, 2013). Therefore, firms that can better access knowledge across borders are more likely to collaborate with foreign firms and file international joint patent applications. At the same time, during the process of cross-border R&D collaboration, firms also need to disclose their own knowledge to partners, which may bring the risk of unintended knowledge spillovers (Lhuillery and Pfister, 2009; Laursen and Salter, 2014). As stated by Cassiman and Veugelers (2002), firms try to minimize the risk of unintended knowledge spillovers while maximizing the benefits of R&D collaboration. Thus, firms' capability of protecting their own knowledge strengthens the incentive to file international joint patent applications as well.

With advances in digital technology, knowledge is being put in the form of digital data (Guellec and Paunov, 2018). Consequently, digital trade rules that coordinate data flows between countries may affect firms' cross-border R&D collaboration behaviors, particularly with regard to international joint patent applications. Digital trade rules cover a wide range of fields, such as e-commerce, cross-border data flows, data protection, and digital intellectual property rights. On the one hand, cross-border data flows and e-commerce provisions enable firms to conveniently transmit the data required for cross-border R&D collaboration, thereby driving an increase in international joint patent applications. On the other hand, data protection and digital intellectual property rights provisions help reduce the risks of data leakage and unintended knowledge spillovers, enhancing firms' confidence in cross-border R&D collaboration and further boosting international joint patent applications.

To validate this proposition, we use firms' patent data to empirically

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investigate the impact of digital trade rules on international joint patent applications. First, we construct a dataset by combining data from the Trade Agreement Provisions on Electronic Commerce and Data (TAPED) database (Burri and Polanco, 2020) on the implementation of digital trade rules between countries with data from the Bureau van Dijk Orbis Intellectual Property (BvD) database on firms' international joint patent applications. Specifically, we use firms' joint patent applications with foreign partners to measure firms' international joint patent applications. A panel regression controlling for sets of fixed effects suggests that the implementation of digital trade rules has a significant and positive impact on firms' international joint patent applications. This result persists after addressing endogeneity concerns and conducting a series of robustness checks, i.e., replacing measures of variables, refining the sample selection, and adopting alternative econometric specifications.

Second, we find that the impact of digital trade rules on firms' international joint patent applications varies with the types of provisions, the digital intensity of sectors, the geographical contiguity between countries and the types of collaboration entities. In particular, the greatest contributions to firms' international joint patent applications are made by cross-border data flows and data protection provisions, followed by e-commerce provisions, and then digital intellectual property rights provisions. However, given the high correlation among different types of provisions, these results should be treated with caution. Regarding the digital intensity of sectors, we find that digital trade rules promote international joint patent applications of firms in high-digital-intensity sectors to a greater extent compared to those in low-digital-intensity sectors. Regarding the geographical contiguity between countries, we discover that digital trade rules play a greater role in promoting joint patent applications between firms in non-contiguous countries compared to those otherwise. As for the types of collaboration entities, we find that digital trade rules significantly facilitate international joint patent applications in firm-firm and firm-research institution collaboration entities but have an insignificant impact on international joint patent applications in research institution-research institution collaboration entities.

Third, we illustrate that digital trade rules promote firms' international joint patent applications via a key mechanism, namely through reducing digital regulatory differences between countries. By examining data based on the Digital Service Trade Restriction Index Heterogeneity (DSTRIH) indices, we demonstrate that digital trade rules reduce digital regulatory differences between two countries, thereby lowering compliance costs for cross-border data flows and fostering international joint patent applications.

Finally, we measure (i) the breadth of international joint patent applications by the number of firms' foreign partners and the number of firms' collaborative technological fields, and (ii) the depth of international joint patent applications by determining firms' total number of joint patents filed with foreign partners and then dividing this value by firms' total number of foreign partners. Our findings indicate that digital trade rules positively impact both the breadth and depth of international joint patent applications. Furthermore, we measure the quality of international joint patent applications based on the number of granted patents, the average number of claims in granted patents, the number of triadic patents, and the average technological complexity of patents. We discover that digital trade rules promote the quality of international joint patent applications.

This paper makes the following novel contributions to the literature. First, we broaden the research on digital trade rules from trade effects to innovation effects. Prior studies show that digital trade rules increase international trade, especially digital trade (Herman and Oliver, 2023; López González et al., 2023; Suh and Roh, 2023; Ma et al., 2024). In contrast, this paper further utilizes joint patent applications data to demonstrate that digital trade rules promote firms' international joint patent applications. This expands the understanding of the impact of digital trade rules from trade facilitation to innovation promotion.

Second, this paper enriches the literature on the determinants of international collaborative innovation. While existing literatures focus on traditional factors such as geographical distance, language barriers, and cultural differences (Guellec and Van Pottelsberghe de la Potterie, 2001; Picci, 2010; Tenzer et al., 2021; Fu et al., 2022), this paper investigates how digital trade rules within preferential trade agreements (PTAs) shape firms' international collaborative innovation, particularly through international joint patent applications.

Third, our results offer a nuanced understanding of how digital trade rules promote the breadth and depth of international joint patent applications. Prior studies on joint patent applications predominantly focus on quantity and quality (Briggs, 2015; Brockman et al., 2018; Hsu et al., 2025). This paper further captures the breadth of international joint patent applications by the number of foreign partners and the diversity of collaborative technological fields, and the depth by the average number of joint patents per foreign partner. These metrics help reveal the sources of the increase in firms' international joint patent applications.

The remainder of this paper is organized as follows. In Section 2, we conduct a literature review and propose hypotheses. In Section 3, we describe the data and empirical strategy. In Section 4, we conduct the benchmark regression, endogeneity tests, and robustness checks and heterogeneity tests. In Section 5, we present the possible mechanism and further analysis. In Section 6, we present our conclusion and discussion.

2. Literature review and hypothesis development

2.1. Literature review

2.1.1. Firms' motivations for R&D collaboration and joint patent applications

To overcome technological bottlenecks, firms tend to undertake R&D collaboration with external partners to jointly develop new technologies. Joint patent applications provide legal protection for these technological outcomes, ensuring collaborating parties to share intellectual property rights (Hagedoorn et al., 2003; Kim and Song, 2007; Hashimoto et al., 2012). Existing literature establishes multiple motivations for firms' R&D collaboration, primarily including sharing R&D risks and costs (Bayona et al., 2001; Bönte and Keilbach, 2005), achieving economies of scale and scope (Mariti and Smiley, 1983), gaining access to complementary knowledge (Sakakibara, 1997; Cassiman and Veugelers, 2002; Miotti and Sachwald, 2003; Robin and Schubert, 2013), and seeking market access (Dodgson, 1992; Hagedoorn, 1993; von Zedtwitz and Gassmann, 2002). The pursuit of external complementary knowledge is a key motivation for domestic and international R&D collaboration identified in the resource-based view literature (Arranz and de Arroyabe, 2008; Choi and Beamish, 2013). The resource-based view posits that a firm is a collection of resources—such as financial capital, machinery, skilled personnel, proprietary technological knowledge (Wernerfelt, 1984). These resources, particularly knowledge-based ones, are not perfectly mobile, imitable, and substitutable, constituting the foundation for firms' sustained competitive advantage (Barney, 1991; Peteraf, 1993). As technology becomes increasingly complex, firms cannot rely solely on internal knowledge for R&D, but instead leverage external knowledge to address technological development constraints (Ahuja, 2000). However, firms' knowledge resources are hard to circulate in the market, prompting firms to engage in R&D collaboration with external partners in order to access complementary knowledge (Das and Teng, 2000). If no suitable partners with complementary knowledge are available within the national innovation system, firms will cross national boundaries to seek foreign partners (Srholec, 2015). Miotti and Sachwald (2003) find that French firms tend to choose partners from the United States (US) in sectors where the US has the strongest technological advantage to acquire key complementary knowledge.

Meanwhile, during the process of R&D collaboration, firms also need to disclose their own knowledge to partners besides acquiring external knowledge. This bidirectional exchange of knowledge accelerates the R&D process. However, it also carries the risk of unintended knowledge spillovers (Lhuillery and Pfister, 2009; Laursen and Salter, 2014; Gorbatyuk et al., 2016). Especially when cooperating with competitors, the unintended spillover of core knowledge may severely undermine firms' competitive advantage (Heiman and Nickerson, 2004). Therefore, when making R&D collaboration decisions, firms typically consider appropriability conditions and adopt a range of knowledge protection mechanisms, including legal protection (e.g., patents, design patterns, trademarks, and copyrights) and strategic protection (e.g., secrecy, technological complexity, and lead time) to strengthen control over their own knowledge and prevent unintended leakage (Cassiman and Veugelers, 2002). Prior research suggests that more favorable appropriability conditions motivate firms to pursue R&D collaboration and enhance the probability of successful collaboration (Cassiman and Veugelers, 2002; Bönte and Keilbach, 2005; Lhuillery and Pfister, 2009; Arvanitis and Bolli, 2013). Cassiman and Veugelers (2002) and Bönte and Keilbach (2005), for instance, find that more effective strategic protection enhances firms' control over commercially sensitive information, reduces the risk of free-riding by both partners and non-partners, and thus encourages firms to engage in R&D collaboration. Arvanitis and Bolli (2013) demonstrate that firms' legal means to protect innovation returns not only promote domestic collaboration but also foster international cooperation, with a more significant impact on the latter. In addition, Lhuillery and Pfister (2009) confirm that industry-level legal appropriability conditions significantly shrink the risk of firms' R&D collaboration.

2.1.2. Impact of digital trade rules

Previous studies confirm that tariff reduction and investment provisions facilitate the cross-border flow of products and capital, thereby enhancing technology spillovers (Jinji et al., 2019; Martínez-Zarzoso and Arregui Coka, 2025). For example, imports of intermediate products containing advanced foreign technologies allow these technologies to be implicitly applied in the production of final goods (Keller, 2004). The flow of foreign direct investment also diffuses technology toward domestic firms (Haskel et al., 2007; Keller and Yeaple, 2009). In addition, several factors such as the advancements in transportation infrastructure (Bahar et al., 2023), development of the internet (Keller and Yeaple, 2013) and high-skilled immigrants (Ganguli, 2015) also contribute to knowledge diffusion. Compared to these provisions and factors, the implementation of digital trade rules can directly reduce barriers to cross-border data flows (Froese, 2019; Azmeh et al., 2020), enabling firms to better share and access knowledge across borders, thus influencing their international innovation collaboration behavior.

However, existing literature on digital trade rules mainly focuses on their trade effects. Studies based on trade data reaches a consensus that digital trade rules significantly promote international trade, especially digital trade (Suh and Roh, 2023; López González et al., 2023; Herman and Oliver, 2023; Wu et al., 2023; Ma et al., 2024). Suh and Roh (2023) use cross-border trade in information and communication technology services as a proxy of digital trade flows and find that a trade agreement incorporating digital trade-related provisions leads to an increase in digital trade flows between a pair of countries. López González et al. (2023) emphasize that digital trade rules play an increasingly significant role in reducing trade costs and increasing trade across countries, regardless of their level of development.

Beyond the impact on trade, digital trade rules also shape innovation activities. A substantial body of research supports that the flow of data across borders has a positive impact on innovation (World Economic Forum, 2016; Global data alliance, 2021a). Hence, Cory (2019) argues that countries should allow the free flow of data across borders to maximize innovation potential. However, in practice, some countries implement data localization under the pretext of ensuring data security, which restricts the cross-border flow of data and hinders innovation (Cory and Dascoli, 2021). In fact, storing data in only local servers does not bolster data security (Chander and Lê, 2015). According to the Business Software Alliance (2017), centralized data storage is less secure than data distributed across large infrastructures, as it increases the likelihood of unauthorized third parties breaching these data "honeypots," leading to severe negative consequences. Furthermore, several studies show that higher standards of data protection positively influence data flows between member countries by fostering trust (Spiezia and Tscheke, 2020). Specifically, the World Economic Forum (2020) notes that compatibility or interoperability in data protection policies enhances the certainty and security of cross-border data flows. However, few have kept an eye on how digital trade rules affect firms' incentive to participate in cross-border collaborative innovation, let alone discussing the underlying mechanism.

2.2. Hypothesis development

2.2.1. The relationship between digital trade rules and international joint patent applications

As previously stated, firms that seek to acquire external knowledge while effectively preventing unintended spillovers of their own knowledge are more likely to engage in cross-border R&D collaboration (Miotti and Sachwald, 2003; Cassiman and Veugelers, 2002), which in turn drives up international joint patent applications.

In the digital era, the exchange of digitalized knowledge, i.e., knowledge in digital form, drives all the way through R&D collaboration (Guellec and Paunov, 2018). The implementation of cross-border data flows provisions makes it easier for firms to share digitalized knowledge across borders, thus effectively fostering cross-border R&D collaboration and boosting joint patent applications with foreign partners. More specifically, before the initiation of R&D collaboration, cross-border data flows enable firms to seamlessly access foreign databases, research reports, and patent literature via the internet. Convenient cross-border access to information significantly attenuates the time and economic costs for firms to search for foreign collaborators. In addition, cross-border data flows enable firms to post R&D collaboration needs on social media platforms and professional network communities and share knowledge with potential foreign partners (Faraj et al., 2011; Nisar et al., 2019), thus creating opportunities for joint patent applications. During the R&D collaboration process, cross-border data flows support real-time sharing of experimental data, model validation, and technical exchanges. By accelerating the circulation of data and knowledge, firms can substantially shorten R&D timelines and boost the success of collaborative innovation (Global data alliance, 2021b). Likewise, e-commerce provisions, such as non-discriminatory treatment of digital products can promote fair competition in digital tools and platforms (Suh et al., 2024). This allows firms to access digitalized knowledge across borders by utilizing superior digital tools and platforms, thereby establishing a conducive environment for international joint patent applications.

However, the risk of proprietary data and knowledge leakage that firms encounter in joint R&D may hinder their participation in cross-border R&D collaboration and thus restrict their joint patent applications with foreign partners. The implementation of data protection provisions can reduce the risk of leakage of proprietary data and knowledge and thus build firms' trust and confidence in cross-border data and knowledge protection. This certainly is key to promoting firms' cross-border R&D collaboration and international joint patent applications. For example, by aligning domestic data protection regulations with international standards, member countries can significantly improve the compatibility and interoperability of data protection policies, and then enhance the security and certainty of cross-border data and knowledge flows (World Economic Forum, 2020). Meanwhile, the implementation of digital intellectual property provisions can provide legal protection for firms' digital knowledge (such as software and source code) (Słok-Wódkowska and Mazur, 2022), effectively preventing their digital knowledge from being illegally copied or leaked by partners and non-partners. This legal protection strengthens firms' control over their own data and knowledge, further minimizing their concern to engage in cross-border R&D collaboration and international joint patent applications. Based on the above-mentioned arguments, we propose the following hypothesis:

Hypothesis 1. The implementation of digital trade rules drives up firms' international joint patent applications.

2.2.2. *Reducing digital regulatory differences as a key mechanism*

Significant digital regulatory differences exist across countries in areas such as e-commerce, cross-border data flows, data protection, and digital intellectual property rights. These differences create substantial barriers to cross-border R&D collaboration, ultimately hindering international joint patent applications. For instance, divergent data transfer and protection mechanisms between countries pose considerable challenges for firms' cross-border data exchanges (World Economic Forum, 2020). Certain countries, such as China, require data transferors that exceed certain thresholds to pass a security assessment by the regulator,[1] while others, like Russia, stipulates that operators must notify all transfers, specifying the categories of data, destination and purpose of the transfer. These regulatory differences compel firms to invest more resources to comply with the diverse requirements across countries (Fritz and Giardini, 2023), thereby diminishing the efficiency of cross-border data transmission critical for R&D collaboration and adversely affecting the process of international joint patent applications. Additionally, some firms may forgo collaboration opportunities with certain countries to avoid the high compliance costs. This limits the internationalization of their R&D efforts and patent applications.

Moreover, as mentioned earlier, in cross-border R&D collaboration, firms inevitably expose their technology and knowledge to partners. At this point, intellectual property rights, as a legal framework of protecting firms' technology and knowledge, becomes particularly critical (Lhuillery and Pfister, 2009; Arvanitis and Bolli, 2013). However, in international collaboration, the enforcement of intellectual property rights, especially digital ones, is not always guaranteed. Protection levels significantly differ across countries, and certain countries may, in practice, limit the protection of specific technologies (Oxley, 1999). To prevent knowledge and technology leakage, firms may restrict collaboration with countries that have weak digital intellectual property rights protection (Hagedoorn et al., 2005). Consequently, this reduces opportunities for cross-border R&D collaboration and adversely affects international joint patent applications.

However, after digital trade rules come into effect, member countries need to revise their domestic digital regulatory policies to ensure compliance with these rules. This helps promote the convergence of digital regulatory measures between member countries, reducing digital regulatory differences. As digital regulatory measures align across countries, firms will experience a dramatic reduction in compliance burdens related to cross-border data flows and data protection, and concerns about digital intellectual property rights. This, in turn, will actively facilitate cross-border R&D collaboration and boost international joint patent applications. Based on the abovementioned arguments, we propose the following hypothesis:

Hypothesis 2. The implementation of digital trade rules increases firms' international joint patent applications through reducing digital regulatory differences between countries.

3. Data and methods

In this section, we first introduce the dataset we use to address the research objectives and present some stylized facts regarding the development of digital trade rules and international joint patent applications. Subsequently, we present the econometric specification.

3.1. *Data sources*

Our empirical analysis is based on two datasets: a global joint patent applications activity dataset containing information on involved firms and their locations, and a country-level pair-wise digital trade rules dataset. The main data sources are presented below.

3.1.1. *International joint patent applications data source*

The BvD database consists of patent-based data that contain detailed information on global patents, such as the associated patent offices; publication numbers; publication dates; application dates; and the applicants' names, country codes, and BvD ID numbers.[2] To be consistent with firms' international joint patent applications, we identify the samples whose original applicants are composed of firms rather than individuals from two different countries, e.g., firm 1 in country A and firm 2 in country B.[3] Moreover, due to the European Union's (EU) deep political and economic integration, EU firms have stronger motivations to jointly apply for patents, which may introduce estimation bias. Hence, all patent records with co-applicants that are both EU firms are excluded from the analysis. In 2000, the US officially enacted the American Inventors Protection Act (AIPA), which requires all patent applications to be published at the USPTO.[4] Thus, we set 2001 as the first year of our sample. In addition, only a few countries worldwide have systems that allow filing of utility models and design patents, and information on these patents is published only upon issuance.[5] Thus, we restrict our sample to invention patents to ensure that patents filed in different countries are comparable. Additionally, considering that patents are typically published 18 months after the earliest filing date and granted 3–4 years after this date,[6] we set 2020 as the final year of our sample to avoid truncation bias.

Subsequently, we clean the data via three steps. First, to avoid

[1] Data processors providing data to foreign countries must declare a data export security assessment if any of the following conditions are met:(1)Critical information infrastructure operators provide personal information or important data to foreign countries;(2)Data processors other than critical information infrastructure operators provide important data to foreign countries, or from January 1 of the current year, cumulatively provide personal information of more than 1 million individuals (excluding sensitive personal information) or sensitive personal information of more than 10,000 individuals to foreign countries.

[2] Each firm has a unique applicant BvD ID number in the database.

[3] In a patent application process, the smaller the number of applicants, the larger the contribution of each applicant to the development of the patent. Additionally, through data cleaning, we find that at least 80 % of the patents in the entire sample of corporate patents are jointly filed by two firms. Therefore, we only consider cases in which only two firms jointly apply for a patent.

[4] Prior to the AIPA, patents filed at the USPTO were published only after they were granted. Thus, patent applications that were withdrawn by the applicant or rejected by the USPTO were not published. The AIPA stipulates that patent applications filed on or after November 29, 2000, are subject to an early publication system, which requires patent applications to be published 18 months after the earliest application date.

[5] For example, at the Chinese National Intellectual Property Administration, utility models and design patents are disclosed when patents are issued. In addition, patent applications that are not granted are not published.

[6] In further analysis, we use granted patents to measure the quality of international joint patents.

Table 1
Summary statistics.

Variable	Mean	SD	Min	Max
Natural log of one plus the number of joint patents	0.1238	0.4180	0	8.1227
Digital trade rules (0/1)	0.1337	0.3403	0	1
Export controls (0/1)	0.3130	0.4637	0	1
Investment provisions (0/1)	0.2182	0.4130	0	1

double-counting of patents that are filed in multiple countries, we count patents at the family level and use the earliest application date to assign the application year.[7] Second, we obtain firm-partner country-year-level international joint patent applications data by aggregating the number of patents a firm jointly applies for with all firms in a specific partner country in a given year. Third, we allocate a value of 0 to a year in which no patents were jointly filed by firms and foreign partners.[8]

3.1.2. Digital trade rules data source

We obtain information on digital trade rules from the TAPED database, which analyzes and scores the provisions related to digital trade rules from more than 430 PTAs concluded since 2000. We use a dummy indicating whether a country pair is involved in a PTA including provisions on digital trade to measure whether digital trade rules come into effect for the country pair.

Next, we prepare a set of digital trade rules at the country-pair level that comprises 2283 country pairs with digital trade rules in force as of the end of 2020.

3.1.3. Other data source

Apart from digital trade rules, other factors such as export controls and investment provisions may influence firms' international joint patent applications behavior. For example, the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies (the Wassenaar Arrangement)[9] has been in effect since 1996 and imposes constraints in specific domains for members exporting to non-member countries. Thus, we establish an export control dummy variable for each country pair and assign this variable a value of 1 if one of the countries is member of the Wassenaar Arrangement while the other is not, and 0 otherwise. Then, we establish an investment provisions dummy variable for each country pair and assign this variable a value of 1 if investment provisions are implemented between two countries, and 0 otherwise. The data on investment provisions are obtained from the United Nations Conference on Trade and Development on International Investment Agreements.

By matching firms' locations with the abovementioned datasets, we obtain an unbalanced panel of 698,472 observations for 2001–2020.[10]

3.2. Descriptive statistics

3.2.1. Summary

Table 1 provides the summary statistics of the aforementioned variables. To deal with zeros in patent observations, we apply a transformation by taking the natural log of one plus the number of patents a firm jointly applies for with all firms in a specific partner country in a given year. Next, we analyze the distribution of global digital trade rules and the changing trends in international joint patent applications.

3.2.2. Distribution of global digital trade rules

Despite the slow progress of multilateral digital trade rule negotiations, various countries have signed agreements including digital trade rules at the regional level to regulate cross-border data flows and promote the development of digital trade. It is evident that digital trade rules are important in the trade agreements of countries with major global economies, as nearly half of their agreements incorporate these rules (Fig. 1). For example, digital trade rules have been included in over 90 % of Canada's agreements and in over 70 % of Australia's and the US's agreements. Similarly, digital trade rules have been included in over 60 % of Singapore's agreements, and Singapore leads Asian countries in this regard.

One of the core objectives of digital trade rules is to establish governance of cross-border data flows. Countries have divergent attitudes toward the governance of cross-border data flows due to differences in multiple factors, such as values, the level of digital economy development, and national policies. Currently, cross-border data flows governance models can be divided into three types: "EU model," "US model," and "Asia-Pacific model." The EU uses personal data protection as the basis for cross-border data transfers. The EU-Japan Economic Partnership Agreement is a representative "EU model" agreement. After Japan received EU's adequacy decision for cross-border data protection, data were able to be transferred from controllers or processors in the EU to Japan without additional authorization. In contrast, the "US model" is based on this country's competitive advantage in digital technology and thus pursues the free flows of cross-border data and prohibits data localization. Representative "US model" agreements include the Comprehensive and Progressive Agreement for Trans-Pacific Partnership and the US-Mexico-Canada Agreement. Finally, a representative "Asia-Pacific model" agreement is the Regional Comprehensive Economic Partnership (RCEP). The RCEP respects each country's regulatory autonomy and actively promotes secure cross-border data flows to ensure that the benefits derived from data-driven developments are shared.

3.2.3. Reconstruction of international joint patent applications

As shown in Fig. 2, the global joint patent applications network underwent two significant changes from 2001 to 2020. First, the network grew denser over this period, indicating that an increasing number of countries joined the network and that countries already in the network continually established new connections. Second, the hierarchical structure of network nodes changed. For example, China gradually moved from the periphery to the core of the network. As a result, in 2020, China became the country with the second-largest number of joint patent applications with foreign partners, surpassing traditional innovation powerhouses such as Japan and Germany. During this period, China's number of collaborating partners also increased significantly, as it established R&D collaborations with countries such as South Korea, Finland, and Switzerland. Meanwhile, the US remained the global leader and maintained the central position in the global joint patent applications landscape. In particular, the thickening of the lines connecting the US to China, the Netherlands, and Germany, respectively, show that the intensity of joint patent applications between the US and its partners increased.

3.3. Empirical strategy

To estimate the impact of digital trade rules on firms' international joint patent applications, we use the following equation:

[7] This paper identifies a simple patent family based on the Family Identifier (Simple) provided by the BvD database and retains only the patent with earliest application date. A simple patent family is a collection of patent documents that have identical content and are filed, published, or approved multiple times in different countries or regions and in inter-regional patent organizations, based on the same priority document.

[8] The regression sample includes only firms that filed at least one international joint patent application during 2001–2020. The firm-level data is sourced from the Bureau van Dijk Orbis Intellectual Property database.

[9] See Appendix A.1 for the list of member countries.

[10] The number of patent records included in the regression sample is 192,440 during 2001–2020. The number of country pairs is 957.

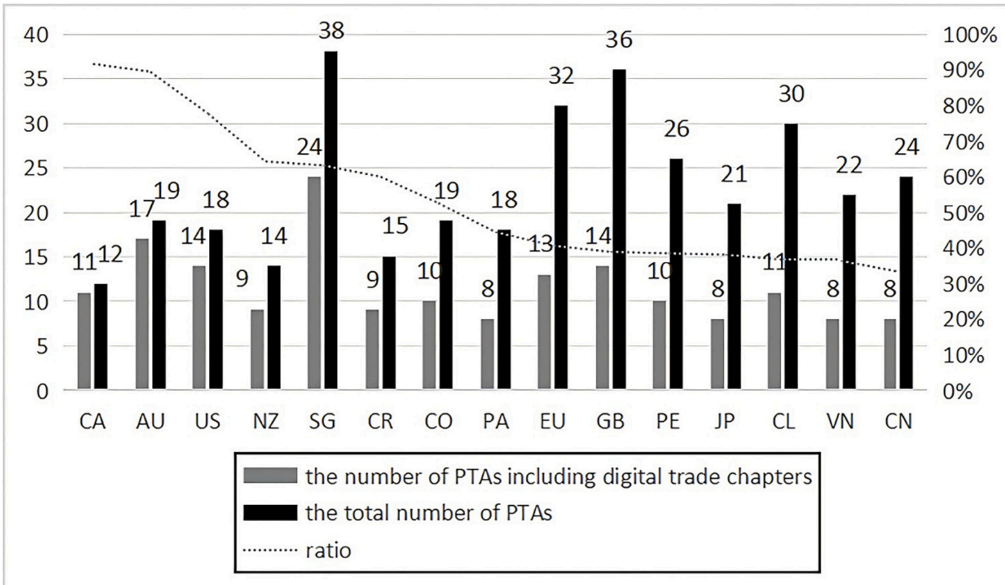


Fig. 1. Achievement of digital trade rules under PTA frameworks by various economies. Notes: Here, we use whether a PTA includes a digital trade chapter to measure whether the economies involved in the PTA implement digital trade rules. The primary vertical axis displays the number of PTAs including digital trade chapters and the total number of PTAs. The secondary vertical axis represents the percentage of PTAs including digital trade chapters relative to the total number of PTAs. The China-Singapore FTA and China-New Zealand FTA have been upgraded, and here we only account for the latest versions. EU PTAs data do not include successive enlargement agreements. In addition, we separately count the number of agreements enacted by the United Kingdom. For simplicity, we use two-digit ISO codes (as defined in Appendix A.2). The data source is the TAPED database, as of November 2023.

$$I_{ihft} = \beta_0 + \beta_1 DTR_{hft} + X_{hft} + \nu_{hf} + \nu_{ht} + \nu_{ft} + \nu_i + \varepsilon_{ihft} \quad (1)$$

where the dependent variable I_{ihft} is the number of invention patents jointly filed by firm i located in home country h and all partner firms located in foreign country f in year t. We apply the transformation ln *(patent + 1)* to deal with zeros in observations.

DTR_{hft} represents digital trade rules and is our key explanatory variable. It captures whether home country h and foreign country f implement digital trade rules in year t. DTR_{hft} takes a value of 1 from the implementation year onward, and 0 otherwise.

X_{hft} represents the control variables for country-pair hf in year t. Given that export controls on high-tech products may inhibit firms' international joint patent applications, we include export controls, proxied by membership in the Wassenaar Arrangement (as mentioned above), as a control variable. Furthermore, effective investment provisions between two countries may influence cross-border capital flow and reshape firms' incentive to jointly innovate. Thus, we incorporate investment provisions as a control variable. Finally, we include several sets of fixed effects. We include home-foreign fixed effects ν_{hf} to eliminate all time-invariant country-pair-specific heterogeneity, such as geographical contiguity and language differences. We also include home-year fixed effects ν_{ht} and foreign-year fixed effects ν_{ft} to account for annual changes in home factors and foreign factors, respectively. Examples of these factors are the innovation capacity, the level of development of the digital economy, the level of intellectual property protection, the level of outward foreign direct investment, the gross domestic product, the per capita income, internet development, and transportation infrastructure in a home country and a foreign country. In addition, we include firm fixed effects ν_i to account for all time-invariant firm characteristics that could influence the international joint patent applications activity of a firm. Moreover, time-varying variables at the firm level hardly affect digital trade rules at the country-pair level but are instead influenced by them. As such, these variables are considered 'bad controls' in previous literature (Cinelli et al., 2024). Consequently, we have not included them in the baseline model to avoid confounding the identification of the causal relationship between digital trade rules and firms' international joint patent applications.[11]

ε_{ihft} is the error term, and standard errors are clustered at the country-pair level to deal with potential heteroskedasticity and serial autocorrelation. The parameter β_1 represents the causal effect of digital trade rules on firms' international joint patent applications.

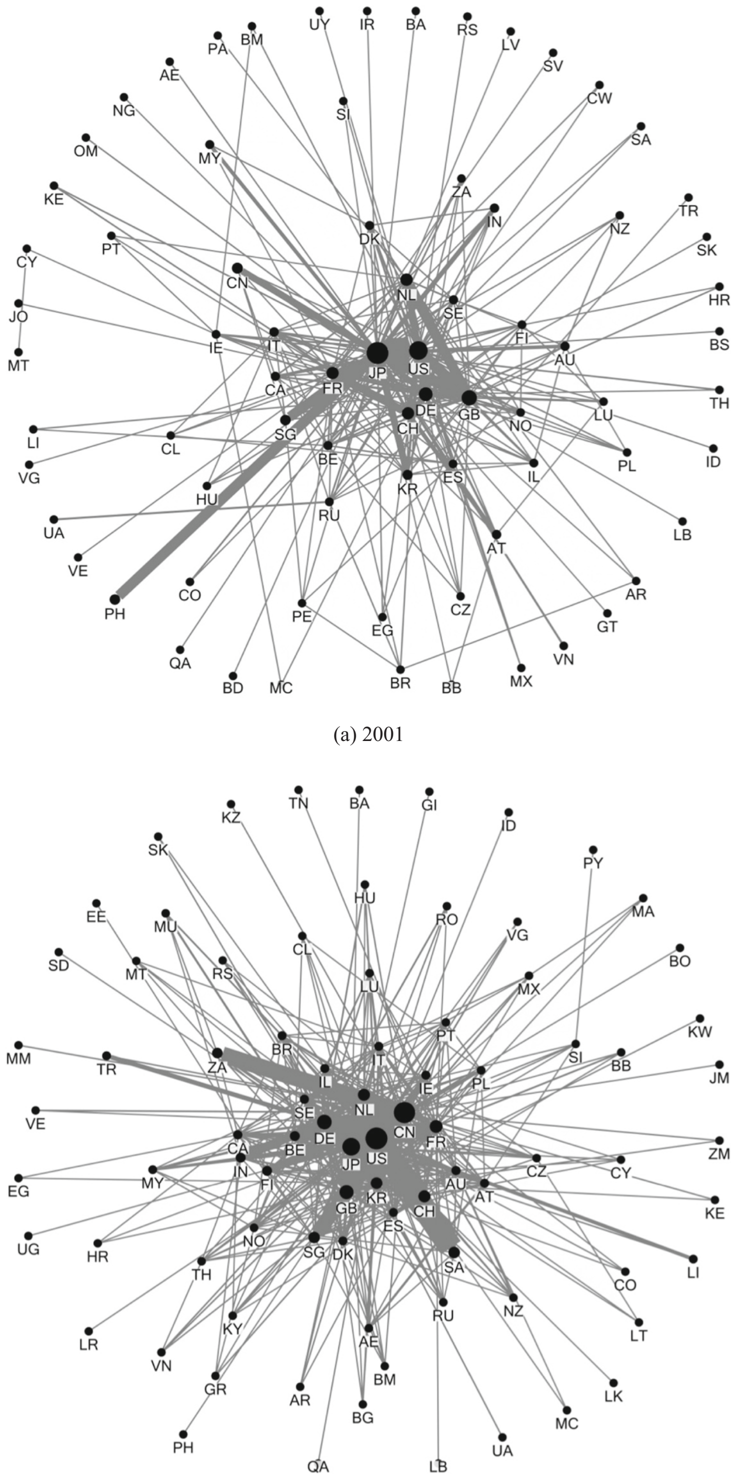
4. Empirical analysis and results

4.1. Baseline results

Table 2 presents the baseline estimates of the model. Column (1) reports the result with only firm, home-year, and foreign-year fixed effects. The estimated coefficient of DTR is significant and positive at the 1 % level, preliminarily confirming that digital trade rules significantly promote firms' international joint patent applications. Column (2) further includes home-foreign fixed effects. The estimated coefficient of DTR remains significant and positive but is smaller than that in Column (1), indicating that there may be country-pair factors missing. Column (3) further includes control variables (export controls and investment provisions). The estimated coefficient of DTR is not substantially different from those in the other columns. This result supports Hypothesis 1, suggesting that a country's participation in a PTA with digital trade rules increases the number of patents jointly filed by a firm in that country and firms in a specific member country by approximately 2.9 %. Taking the year 2020 as an example, we estimate that the implementation of digital trade rules enables firms to capture monetary value ranging from approximately 31,785 to 160,002 US dollars (in 2020 USD) through international joint patent applications.[12]

[11] However, in order to obtain more robust estimates, we include firm-year fixed effects in the subsequent robustness checks.

[12] The detailed calculation method and procedure for the monetary value are provided in Appendix B.



(a) 2001

(b) 2020

Fig. 2. International joint patent applications networks in 2001 and 2020. Notes: The data source is the BvD database. The nodes represent economies, and the links denote the joint patent applications filed by the two corresponding economies. The size of a node is proportional to the total number of joint patent applications filed by the corresponding economy, while the thickness of a link is proportional to the number of joint patent applications filed by the two economies it connects. For simplicity, we use two-digit ISO codes (as defined in Appendix A.2).

4.2. Endogeneity analysis

In the baseline equation, the independent variable, i.e., digital trade rules, is of a higher dimension than the firm-level dependent variables, thereby largely excluding the possibility of reverse causality. Nevertheless, omitted variable bias persists when we do not account for unobservable country pair-level factors that change over time and affect both digital trade rules and firms' international joint patent applications. Therefore, we employ the instrumental variable (IV) approach to address the issue of endogeneity. Specifically, following Neri-Lainé et al.

Table 2
Baseline regression results.

	(1)	(2)	(3)
	International joint patent applications		
DTR	0.0417***	0.0291***	0.0290***
	(0.0142)	(0.0080)	(0.0081)
Export controls (0/1)			−0.0035
			(0.0126)
Investment provisions (0/1)			−0.0062
			(0.0085)
Constant	0.1182***	0.1198***	0.1223***
	(0.0020)	(0.0011)	(0.0046)
Firm FE	Y	Y	Y
Home-foreign FE	N	Y	Y
Home-year FE	Y	Y	Y
Foreign-year FE	Y	Y	Y
Observations	697,559	697,559	697,559
R-squared	0.2022	0.2180	0.2180

Notes: Standard errors are presented in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All tables below, unless stated otherwise, incorporate control variables and fixed effects, and cluster standard errors at the country-pair level.

(2023), the IV is defined as the product of two leave-one-out means. The first component measures the average depth of digital trade rules implemented by country h in year t with countries $k \neq f$ in the same macro region as country f. The second component measures the average depth of digital trade rules implemented by country f in year t with countries $z \neq h$ in the same macro region as country h. Formally, the IV is constructed as:

$$DTR_{hft}^{IV} = \left[\frac{1}{K-1}\sum_{k\neq f} DTR_{hkt}^{d}\right] \times \left[\frac{1}{Z-1}\sum_{z\neq h} DTR_{fzt}^{d}\right] \tag{2}$$

where K and Z denote the number of countries in the macro regions of f and h, respectively. DTR_{hkt}^{d} and DTR_{fzt}^{d} denote the depth of digital trade rules implemented between country h and country k, and between country f and country z, in year t, respectively.[13] As comprehensively explained in section 4.3.1, depth of digital trade rules is the average score of digital trade provisions to assess the extent of legalization. The IV is justified as follows. First, the average depth of digital trade rules implemented by countries h and f with other countries reflects two countries' attitudes toward digital openness and is expected to be strongly correlated with the probability of two countries implementing digital trade rules. Second, the average depth of digital trade rules implemented by two countries with other countries does not directly impact international joint patent applications of firms in two countries. Instead, its impact is mediated by the implementation of digital trade rules between two countries, thereby satisfying the exogeneity and exclusivity conditions of the IV. The estimated coefficient of the first stage is given in Column (1) of Table 3 and is positive. This result indicates that as the average depth of digital trade rules that two countries implemented with other countries increases, the likelihood that digital trade rules are implemented between two countries increases. The results of the second stage are given in Column (2) of Table 3 and show that when endogeneity issues are considered, digital trade rules continue to facilitate firms' international joint patent applications. In particular, the Kleibergen-Paap rank (rk) Lagrange multiplier (LM) statistic significantly rejects the null hypothesis at the 1 % level, indicating that the IV passes the under-identification test. Moreover, the Kleibergen-Paap rk Wald F statistic exceeds the critical value for the weak IV identification test at the 10 % significance level, suggesting that the IV is not weak.

[13] The detailed construction of the depth of digital trade rules is presented in Appendix D.

Table 3
Endogeneity analysis.

	(1)	(2)
	First stage	Second stage
DTR		0.0536***
		(0.0157)
IV	5.4817***	
	(0.5438)	
Kleibergen-Paap rk LM statistic		64.4590
		[0.0000]
Kleibergen-Paap rk Wald F-statistic		101.6300
		{16.3800}
Observations		697,559

Notes: The Kleibergen-Paap rk LM statistic is used to test for under-identification of the IV and its p-value is indicated in square brackets ([]). The Kleibergen-Paap rk Wald F statistic is used to test for weak identification of the IV, with the critical value at the 10 % level obtained from the Stock-Yogo test shown in curly brackets ({}).

4.3. Robustness checks

In this subsection, we conduct a series of robustness checks to confirm the validity of the result. These checks involve replacing measures of variables, refining the sample selection, and adopting alternative econometric specifications.

4.3.1. Replacement of measures of variables

Our benchmark result is obtained by measuring digital trade rules using a dummy that indicates whether a country pair is involved in a PTA with digital trade provisions. However, compared with fragmented digital trade provisions, a dedicated digital trade chapter contains more legally binding digital trade rules and better reflects the extent to which two countries regulate e-commerce, cross-border data flows, data protection and digital intellectual property rights. Accordingly, we use whether a PTA includes a digital trade chapter to measure whether the two countries involved in the PTA have digital trade rules in force. The result in Column (1) of Panel A in Table 4 shows that when two countries implement a PTA that includes a dedicated chapter on digital trade, international joint patent applications of firms in the two countries increases. However, the dummies lack information on digital trade rules' breadth and depth, which also affect firms' motivation to engage in international joint patent applications. Two methods are typically used to measure the breadth of digital trade rules (Wu et al., 2023). The first method divides the number of articles in the digital trade chapter by 10, whereas the second method divides the number of words in the digital trade chapter by 1000. The regression results in Columns (2)–(3) of Panel A in Table 4 demonstrate that the breadth of digital trade rules can significantly promote firms' international joint patent applications. Regarding the depth of digital trade rules, the TAPED database includes an assessment of the extent of legalization of provisions related to digital trade. This assessment distinguishes between "soft" and "hard" commitments, where the former are those that are not enforceable by another party, whereas the latter are those that are enforceable by another party. Moreover, the TAPED database uses the following three-step process to score digital trade provisions. First, if a PTA does not include a digital trade provision, it is scored as 0. Second, if the digital trade provision is not legally enforceable, it is scored as 1. Third, if the digital trade provision is legally enforceable, it is scored as 2. Therefore, we use the average score of digital trade provisions to measure the depth of digital trade rules.[14] The result reported in Column (4) of Panel A in Table 4 shows that the depth of digital trade rules can significantly promote firms' international joint patent applications.

[14] The detailed construction of the depth of digital trade rules is presented in Appendix D.

Table 4
Robustness checks.

Panel A Replacing measures of variables

	(1) Chapter	(2) Breadth, article	(3) Breadth, word	(4) Depth
DTR	0.0130**	0.0172***	0.0075**	0.0269***
	(0.0052)	(0.0050)	(0.0030)	(0.0064)
Observations	697,559	697,559	697,559	697,559
R-squared	0.2179	0.2179	0.2179	0.2179

Panel B Refining the sample selection

	(1) Global ultimate owners	(2) Patent box	(3) Tax haven	(4) Bilateral agreement	(5) Expanded sample
DTR	0.0158***	0.0195**	0.0285***	0.0142**	0.0013**
	(0.0043)	(0.0086)	(0.0096)	(0.0067)	(0.0007)
Observations	621,981	312,233	559,109	558,598	26,026,143
R-squared	0.1732	0.2080	0.2282	0.1905	0.0365

Panel C Adopting alternative econometric specifications

	(1) Firm-foreign county FE	(2) Firm-year FE	(3) Internet connectivity	(4) Sample interval	(5) IHS	(6) Binary indicator
DTR	0.0289***	0.0312***	0.0318**	0.0336***	0.0360***	0.0179***
	(0.0079)	(0.0108)	(0.0141)	(0.0103)	(0.0100)	(0.0039)
Observations	697,551	335,621	570,773	240,504	697,559	697,559
R-squared	0.3637	0.5823	0.2355	0.2403	0.2115	0.1134

4.3.2. *Refinement of sample selection*

Headquarters and affiliates within multinational firms exhibit specialization and managerial links. As a result, patents jointly filed by two firms are highly likely to involve one firm independently conducting R&D while the other firm acts as a "nominal applicant." In such cases, jointly filed patents do not truly represent R&D collaboration. Therefore, based on the information provided by the BvD database regarding the ultimate global owners of firms,[15] we exclude data on joint patent applications filed by firms that have the same ultimate global owner. Subsequently, we recalibrate the count of joint patents based on the applicant, the applicant's country, and the joint applicant's country and then perform a regression analysis. As can be seen in Column (1) of Panel B in Table 4, the estimate generated from this "clean" sample is similar to our baseline result.

Furthermore, country-specific policies may distort the motivation of firms to jointly apply for patents with firms from other countries. One example of such a policy is a patent box regime, which is used to encourage local innovation and incentivize firms to keep intellectual property within their own country. Some countries have widely implemented patent box regimes[16] that reduce corporate tax rates on income derived from intellectual property. Firms from another country may jointly apply for patents with firms located in a country with a patent box to access the low tax rates in this regime. In such a case, jointly filed patents may not truly represent R&D collaboration. Therefore, we exclude samples from firms located in countries with a patent box and then perform a regression analysis. As can be seen in Column (2) of Panel B in Table 4, the resulting estimate remains significant and positive. Another example of a country-specific policy that may distort the incentive to jointly apply for patents is a tax haven, which is a country or territory that offers low tax rates and favorable regulatory policies to foreign investors (Hines Jr, 2010). Firms from another country may jointly apply for patents with firms located in a tax haven to access low tax rates. Therefore, we further exclude samples from firms located in tax havens[17] and then perform a regression analysis. As can be seen in Column (3) of Panel B in Table 4, the resulting estimate remains robust.

Moreover, we minimize the likelihood of reverse causality (i.e., a certain firm in country h or f affecting the signature and content of digital trade rules) by further excluding samples resulting from bilateral agreements. Thus, we perform a regression analysis to examine the impact of digital trade rules implemented by three or more countries on firms' international joint patent applications. The resulting estimate in Column (4) of Panel B in Table 4 shows that digital trade rules still promote firms' international joint patent applications.

In the baseline regression, we restrict the sample to firms that filed at least one international joint patent application during the period 2001–2020. However, excluding firms without such applications may introduce sample selection bias, potentially leading to biased estimates of the effects of digital trade rules. To address this concern, we expand the sample to include firms without international joint patent applications during this period, assigning missing values a value of zero to construct a more comprehensive dataset. As can be seen in Column (5) of Panel B in Table 4, the estimated result from the expanded sample remains significant and positive.

4.3.3. *Adoption of alternative econometric specifications*

Factors that do not change over time at the firm-foreign country level, such as links of firms with particular foreign countries, can also impact firms' international joint patent applications. Thus, we incorporate firm-foreign country fixed effects in an effort to capture these

[15] A firm is considered to be an ultimate owner if it has no identified shareholders or if its shareholders' percentages are not known. The minimum percentage of control in the path from a subject firm to its ultimate owner is 50.01 %.

[16] A patent box, which is also known as an innovation box or an intellectual property box, is implemented to apply lower than normal corporate income tax rates to prescribed forms of income earned by firms through patents and other intellectual property. See Appendix C.1 for a list of countries that apply a patent box.

[17] Tax havens are listed in Appendix C.2.

missing factors. Moreover, dynamic factors such as digital transformation, R&D investment, or other strategic shifts within firms over time can affect firms' international joint patent applications capabilities. Thus, we further incorporate firm-year fixed effects to control for time-varying firm-specific changes. As can be seen in Columns (1) and (2) of Panel C in Table 4, the estimated coefficients remain significant and positive. In addition, internet connectivity between countries may simultaneously influence the implementation of digital trade rules as well as the filing of international joint patent applications. Referring to Herman and Oliver (2023), we use the indicator from the International Telecommunication Union on "International internet bandwidth per internet user" to measure internet connectivity between countries. Given that the indicator is reported at the unilateral level and the quality of internet connectivity between two countries is constrained by the lowest bandwidth capacity, we construct a bilateral measure by taking the minimum value between each country pair. The result in Column (3) of Panel C in Table 4 shows that, after controlling for internet connectivity between countries, digital trade rules still significantly promote international joint patent applications.

Digital trade rules take effect over a certain period. Thus, following Herman and Oliver (2023), we adopt a division method by applying a 3-year interval to re-divide the sample intervals and then perform a regression analysis. As can be seen in Column (4) of Panel C in Table 4, the resulting estimate has the same sign as the baseline regression result.

Next, we use two methods to deal with zeros in patent observations. First, referring to the approach of MacKinnon and Magee (1990) and Liu and Ma (2020), we transform the dependent variable into an inverse hyperbolic sine (IHS) form, which is given by $\ln[y + (1 + y^2)^{0.5}]$, and then perform a regression analysis. As can be seen in Column (5) of Panel C in Table 4, the estimate remains significant and positive. Second, we replace the dependent variable with a binary indicator that equals 1 if the firm has a positive number of joint patent applications filed with foreign partners, and 0 otherwise. Subsequently, following Forge et al. (2024), we use a linear probability model with high-dimensional fixed effects to estimate the impact of digital trade rules on firms' international joint patent applications. As can be seen in Column (6) of Panel C in Table 4, the result shows that the impact remains positive.

4.4. Heterogeneity tests

In this subsection, we investigate whether the impact of digital trade rules on firms' international joint patent applications varies with the types of provisions, the digital intensity of sectors, the geographical contiguity between countries and the types of collaboration entities.

4.4.1. Types of digital trade provisions

The depth of different types of digital trade provisions in PTAs may have varying impacts on firms' international joint patent applications. Thus, we categorize digital trade rules into four types of provisions, namely e-commerce (Ecommerce), cross-border data flows (Flows), data protection (Protection), and digital intellectual property rights (IPR) provisions, and estimate their respective effects.[18] However, a challenge when analyzing their respective effects is that these provisions tend to be included together in a PTA and therefore are highly correlated (Herman and Oliver, 2023). Putting these provisions in one single estimation equation and comparing the magnitude of their coefficients will bring severe multicollinearity issue. Therefore, we only display the coefficients one by one.

As can be seen in Columns (1)–(4) of Table 5, when included alone, all four types of provisions significantly promote firms' international joint patent applications, with cross-border data flows and data protection provisions doing so to the greatest extent. Specifically, cross-border data flows and e-commerce provisions enable firms to

[18] The construction of the indicators is specified in Appendix D.

Table 5
Heterogeneous effects of provisions.

	(1)	(2)	(3)	(4)
Ecommerce	0.0247***			
	(0.0058)			
Flows		0.0326***		
		(0.0085)		
Protection			0.0336***	
			(0.0078)	
IPR				0.0119***
				(0.0037)
Observations	697,559	697,559	697,559	697,559
R-squared	0.2179	0.2179	0.2179	0.2179

Notes: Since some PTAs simultaneously include multiple types of provisions, commonly used methods for testing coefficient differences—such as interaction terms or the Chow test—are not applicable. As a result, direct statistical tests are absent in this context.

conveniently transmit the data required for cross-border R&D collaboration, thereby driving an increase in international joint patent applications. Moreover, data protection and digital intellectual property rights provisions can provide effective protection for firms' data and digital knowledge and therefore foster international joint patent applications. However, given the high correlation among different types of provisions, these results, particularly the coefficient differences, should be treated with caution.

4.4.2. Digital intensity of sectors

The cost reduction of data flows across borders is key to promoting international joint patent applications. Thus, we expect the effect to be greater in sectors with high digital intensity than in those with low digital intensity. We categorize the samples into two subgroups according to a taxonomy of digital intensity sectors (Calvino et al., 2018), namely a high-digital-intensity subgroup and a low-digital-intensity subgroup.[19] Then, we establish a digital-intensity dummy variable for firms' sectors, where a value of 1 indicates high-digital-intensity and a value of 0 indicates low-digital-intensity. We augment Eq. (1) by adding an interaction term with the digital-intensity dummy and then perform a regression.[20] The resulting estimated coefficient for the interaction in Column (1) of Table 6 is significant at the 10 % level. This indicates that digital trade rules promote international joint patent applications of firms in high-digital-intensity sectors to a greater extent compared to those in low-digital-intensity sectors.

4.4.3. Geographical contiguity between countries

Prior research substantiates the belief that knowledge flows tend to be confined within geographical boundaries of cities, states, or countries (Jaffe et al., 1993; Jaffe and Trajtenberg, 1999; Breschi and Lissoni, 2001; Bottazzi and Peri, 2003; Peri, 2005; Feldman and Kogler, 2010). So geographical disconnection is considered quite a main barrier to cross-border knowledge flows. The implementation of digital trade rules can reduce the friction of geographical disconnection for the diffusion of knowledge. These rules, particularly the cross-border data flows

[19] Calvino et al. (2018) provide a taxonomy of digital intensity sectors based on the share of tangible information and communication technology (ICT) and intangible (i.e., software) investment; the share of purchases of intermediate ICT goods and services; the stock of robots per hundreds of employees; the share of ICT specialists in total employment; and the share of turnover from online sales. We group "high-digital-intensity sectors" with "medium-digital-intensity sectors" and group "medium-low-digital-intensity sectors" with "low-digital-intensity sectors." The specific classification of sectors can be found in Appendix E.

[20] Since a firm's sector is hardly time-invariant, it can be absorbed by firm fixed effects and therefore does not need to be included separately in the equation.

Table 6
Heterogeneous effects of digital intensity, geographical contiguity and the types of collaboration entities.

	(1)	(2)	(3)	(4)	(5)
	Digital_intensity	Contiguity	Firm-firm	Firm-research institution	Research institution-research institution
DTR	0.0193***	0.0300***	0.0361***	0.0374***	0.0239
	(0.0072)	(0.0084)	(0.0107)	(0.0129)	(0.0237)
DTR × Digital_intensity	0.0183*				
	(0.0105)				
DTR × Contiguity		−0.0297**			
		(0.0137)			
P-value (Col 3 vs. 4)			0.9133		
P-value (Col 3 vs. 5)			0.6041		
P-value (Col 4 vs. 5)			0.5558		
Observations	652,709	695,195	598,796	111,519	15,283
R-squared	0.2161	0.2183	0.2266	0.3629	0.3542

Notes: As values are missing for some firms and country pairs, the observations in the regressions reported in Columns (1) and (2) of Table 6 are not consistent with those in the benchmark regression. The *p*-values for the differences between Columns (3) and (4), (3) and (5), and (4) and (5) are 0.9133, 0.6041, and 0.5558, respectively—all exceeding the 0.1 threshold—indicating that the coefficients across these three columns are not statistically significantly different.

provisions, allow firms to seamlessly share data and digitalized knowledge disregarding geographical characteristics. This, in turn, will foster cross-border R&D collaboration at greater margin between those more geographically isolated firms.

Hence, we predict that digital trade rules play a greater role in promoting joint patent applications between firms in non-contiguous countries compared to those in geographically contiguous countries. Then, we establish a contiguity dummy variable for country pairs, where a value of 1 indicates contiguity and a value of 0 indicates non-contiguity.[21] We augment Eq. (1) by adding an interaction term with the contiguity dummy and then perform a regression. The resulting estimated coefficient for the interaction in Column (1) of Table 6 is significant at the 5 % level, which supports our prediction.

4.4.4. *Types of collaboration entities*

The incentives for R&D and forms of output vary across types of collaboration entities.[22] Thus, we categorize joint patent applications into three groups, namely firm-firm, firm-research institution, and research institution-research institution joint patent applications, and then perform three regressions. The results in Columns (3)–(5) of Table 6 show that digital trade rules facilitate international joint patent applications in firm-firm and firm-research institution collaboration entities but do not significantly impact international joint patent applications in research institution-research institution collaboration entities. These results are attributable to the fact that research institutions are predominantly universities, which tend to produce academic papers rather than patents. However, to ensure statistical rigor, we use Seemingly Unrelated Estimation (SUEST) to compare coefficients across three groups and find no significant difference.

5. Mechanism and further analysis

5.1. *Mechanism*

We now extend our discussion to examine Hypothesis 2 we propose regarding the possible mechanism through which digital trade rules affect firms' international joint patent applications.

Hypothesis 2 posits that digital trade rules promote firms' international joint patent applications through reducing digital regulatory differences between countries. In accordance with Ferracane and van der Marel (2023), we use the DSTRIH indices developed by the OECD as a proxy for digital regulatory differences.[23] Table 7 reports the results of a regression with DSTRIH indices as the mediator variable. In Column (1), the estimated coefficient of DTR is 0.0116, which is significant at the 10 % level. This result indicates that digital trade rules have a positive impact on firms' international joint patent applications. The estimated coefficient of DTR in Column (2) is negative and significant at the 1 % level. This result suggests that digital trade rules can reduce digital regulatory heterogeneity between two countries and promote consistency in digital regulatory policies. In Column (3), the estimated coefficient of DSTRIH is negative and significant at the 1 % level, and the estimated coefficient of DTR is 0.0086 (< 0.0116). These results confirm that reducing digital regulatory heterogeneity between countries is an important mechanism through which digital trade rules facilitate firms' international joint patent applications.

Table 7
Mechanism.

Digital regulatory heterogeneity			
	(1)	(2)	(3)
	International joint patent applications	DSTRIH	International joint patent applications
DTR	0.0116*	−0.0122***	0.0086
	(0.0066)	(0.0042)	(0.0064)
DSTRIH			−0.1901***
			(0.0727)
Observations	236,439	7919	236,439
R-squared	0.3187	0.9596	0.3187

Notes: As DSTRIH values are missing for some country pairs in specific years, the observations in the regressions reported in Table 7 are not consistent with those in the benchmark regression. Moreover, since the regression of DSTRIH on DTR is conducted at the country-pair level, the observations in the regression reported in Column (2) of Table 7 is smaller than those in the other two columns.

[21] The geographical contiguity indicator is sourced from le Centre d'Études Prospectives et d'Informations Internationales. https://cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=32. Since geographical contiguity between countries is time-invariant, it can be absorbed by country-pair fixed effects and therefore does not need to be included separately in the equation.

[22] We classify applicants whose names contain the words "ACADEMY," "UNIVERSITY," "COLLEGE," or "INSTITUTE" as research institutions.

[23] The indices can be constructed based on the OECD Digital Services Trade Restrictiveness Index (DSTRI). The DSTRI covers policy restrictions in digital services and is available for the 2014–2022 period across 85 countries. The policy restrictions are applied in five areas: infrastructure and connectivity, electronic transactions, payment systems, IPRs, and other barriers affecting trade in digitally enabled services (Ferencz, 2019). Each area covers several measures. Therefore, for each country pair, the DSTRIH value represents the (weighted) share of measures for which two countries have a different regulation "answer". The DSTRIH value varies from 0 to 1, with a large value indicating that there are high digital regulatory differences between the two countries of interest.

Table 8
Breadth and depth of international joint patent applications.

	(1)	(2)	(3)
	Number of foreign partners	Number of technological fields	Average number of joint patents
DTR	0.0146***	0.0239***	0.0264***
	(0.0029)	(0.0067)	(0.0080)
Observations	697,559	682,890	697,559
R-squared	0.1426	0.1787	0.2101

5.2. Further analysis

5.2.1. Breadth and depth of international joint patent applications

We next explore the reasons for the increase in firms' international joint patent applications. To this end, we decompose the scale of international joint patent applications into two dimensions, namely breadth and depth. We use two indicators to measure the breadth of international joint patent applications, namely the number of firms' foreign partners, and the number of technological fields in which firms and their foreign partners co-operate. As in the baseline equation, we aggregate the number of firms' foreign partners in a given year based on the applicant, the applicant's country, and the joint applicant's country. In addition, we assign the technological field of a patent based on the primary International Patent Classification (IPC) subclass, i.e., by using the four-digit IPC codes.[24] Next, in the same manner, we aggregate the number of technological fields in which firms and their foreign partners co-operate. Furthermore, we use one indicator to measure the depth of international joint patent applications, namely the total number of firms' joint patents filed with foreign partners divided by the total number of foreign partners. Subsequently, we perform the corresponding regressions and, as shown in Table 8, the results demonstrate that digital trade rules increase the breadth and depth of international joint patent applications.

5.2.2. Quality of international joint patent applications

In general, patent offices only grant patents for high-quality patent applications. Thus, following Hegde et al. (2023), we use the number of granted patents jointly owned by firms and their foreign partners to measure the quality of firms' international joint patent applications. Moreover, the number of independent and dependent claims in a patent reflects the breadth of applicability and the value of a patent. Independent claims typically encapsulate the technical solution of the patent, as they record the technical features necessary for solving a technical problem. The collection of these features defines the maximum scope of protection of a patent. Dependent claims build upon independent claims by adding technical features. The quantity of dependent claims also reflects the scope of protection. Thus, compared with a patent with a smaller scope of protection, a patent with a larger scope of protection is of higher quality. Therefore, following Lanjouw and Schankerman (2004), we use the average number of claims in granted patents jointly owned by firms and their foreign partners to measure the quality of firms' international joint patent applications. A triadic patent family is a set of patents filed at three major patent offices: the European Patent Office (EPO), the Japan Patent Office, and the USPTO. Compared with other patents, triadic patents have higher technological content and economic value. Therefore, following Aghion et al. (2023), we also use the number of triadic patents filed jointly by firms and their foreign partners to measure the quality of firms' international joint patent applications. The results of the regressions are reported in Columns (1)–(3) of Table 9 and show that digital trade rules increase the quality of firms' international joint patent applications.

Compared with simple innovation, complex innovation typically requires greater R&D investment, involves more intricate knowledge, and possesses higher technological complexity. Hence, we also use technological complexity to measure the quality of international joint patent applications. Specifically, we exploit the structural diversity indicator proposed by Broekel (2019) to measure technological complexity. Broekel (2019) uses patent applications data from the EPO to calculate the technological complexity of 655 Cooperative Patent Classification (CPC) subclasses from 1980 to 2015. We average the data from 2001 to 2015 and use the CPC-IPC concordance table to map the technological complexity measured at the CPC level to four-digit IPC codes. Then, we determine the technological complexity of individual patents based on the primary four-digit IPC codes. Finally, we assess the complexity of firms' international joint patent applications by calculating the average complexity of patents filed jointly by firms and their foreign partners. The result of the regression is given in Column (4) of Table 9 and shows that digital trade rules enhance the technological complexity of firms' international joint patent applications.

6. Conclusion and discussion

6.1. Contributions to the literature

Digital trade rules aimed at coordinating cross-border data flows inevitably reshape firms' international joint patent applications behavior. Accordingly, in this paper, we use data from the TAPED and BvD databases to study the impact of digital trade rules on firms' international joint patent applications. We find that the implementation of digital trade rules can significantly promote firms' international joint patent applications.

Moreover, we use the average depth of digital trade rules implemented by two countries with other countries as the IV and find that this result holds after addressing endogeneity concerns. To account for measurement errors and biases in the estimation methods, we conduct a series of robustness checks (i.e., replacing measures of variables, refining the sample selection, and adopting alternative econometric specifications) and find that digital trade rules still have a significant and positive on firms' international joint patent applications.

Additionally, our mechanism analysis suggests that digital trade rules can promote firms' international joint patent applications through reducing digital regulatory differences between countries. Furthermore, we find that the impact of digital trade rules exhibits heterogeneity, as follows: (1) Compared with e-commerce and digital intellectual property provisions, cross-border data flows and data protection provisions are most effective in promoting firms' international joint patent applications. However, given the high correlation among different types of provisions, these results should be treated with caution. (2) Digital trade rules promote international joint patent applications of firms in high-digital-intensity sectors to a greater extent compared to those in low-digital-intensity sectors. (3) Digital trade rules play a greater role in promoting joint patent applications between firms in non-contiguous countries compared to those in geographically contiguous countries. (4) Digital trade rules facilitate international joint patent applications in firm-firm and firm-research institution collaboration entities but have an insignificant effect on international joint patent applications in

Table 9
Quality of international joint patent applications.

	(1)	(2)	(3)	(4)
	Granted	Claim	Triadic	Technological complexity
DTR	0.0242***	0.0478***	0.0206***	0.0396***
	(0.0063)	(0.0097)	(0.0061)	(0.0097)
Observations	435,690	435,690	139,571	679,781
R-squared	0.2316	0.1189	0.1825	0.1023

[24] The sample size is smaller than the baseline regression as information on the primary IPC subclass of some patents is missing.

research institution-research institution collaboration entities. Finally, we find that digital trade rules increase the breadth, depth, and quality of firms' international joint patent applications.

This study contributes primarily to two strands of the academic literature. First, this study contributes to the literature on the effects of digital trade rules. Existing literature on digital trade rules mainly focuses on their trade effects (Suh and Roh, 2023; López González et al., 2023; Herman and Oliver, 2023; Wu et al., 2023; Ma et al., 2024). Beyond the impact on trade, digital trade rules also influence innovation. Using firms' joint patent applications with foreign partners as a proxy for international joint patent applications, we provide evidence that the implementation of digital trade rules significantly promotes firms' international joint patent applications.

Moreover, this study contributes to the literature on the determinants of international collaborative innovation. Previous studies primarily examine how traditional factors, e.g., geographical distance, language barriers, and cultural differences affect international collaborative innovation (Guellec and Van Pottelsberghe de la Potterie, 2001; Picci, 2010; Tenzer et al., 2021; Fu et al., 2022). In contrast, we emphasize the role of emerging digital trade rules in enabling such collaboration, particularly by promoting international joint patent applications. Indeed, cross-border data flows and e-commerce provisions facilitate the transmission of R&D-related data, thereby promoting international joint patent applications. Meanwhile, data protection and digital intellectual property rights provisions help reduce the risks of data leakage and unintended spillovers, further encouraging such applications.

6.2. Practical implications

Overall, this study deepens our understanding of the impact of digital trade rules on firms' international joint patent applications. The findings, particularly those from the heterogeneity analysis, offer practical insights for countries, industries, and firms. The finding regarding heterogeneity in digital trade provisions demonstrates that e-commerce, cross-border data flows, data protection and digital intellectual property provisions all significantly promote international joint patent applications. Therefore, from a policy perspective, countries should promote the development and adoption of these provisions through multilateral, regional, and bilateral frameworks. For instance, at the multilateral level, countries are encouraged to actively join the WTO *E*-commerce Joint Statement Initiative (JSI), seek consensus on the key digital trade provisions, and help establish a set of global digital trade rules. At the regional and bilateral level, when upgrading existing PTAs or negotiating new ones, countries should prioritize the inclusion of these digital trade provisions and strengthen the applicability of dispute settlement mechanisms to ensure their enforceability. These efforts will enable countries to more effectively integrate into the global innovation network and boost their technological innovation capacity.

Moreover, the heterogeneity result based on industry digital intensity indicates that digital trade rules impose the greatest impact on firms in high-digital-intensity industries, suggesting that industries and firms should proactively adapt to the digital environment in order to fully realize its potential benefits. Given that different industries have varying types and volumes of cross-border data flow needs, it is essential for them to provide timely and accurate feedback to governments regarding their specific data transfer requirements. Such feedback can facilitate the development of targeted and effective digital trade policies. At the same time, firms should spontaneously pursue digital transformation by adopting advanced technologies, enhancing the digital competencies of their workforce, and establishing robust data governance systems to better support international joint patent applications.

6.3. Limitations and future research

Despite the robustness of our results across various specifications, this study is bound to certain limitations. First, due to data availability, we solely examine the impact of digital trade rules on firms' international joint patent applications. Broadly speaking, collaborative innovation driven by digital trade rules may also take the form of joint product development or other types of innovation. Moreover, certain innovation outcomes may not be patented due to the strategic use of trade secrets. Future research could therefore utilize firm-level survey data on innovation activities to better capture the diversity of collaborative innovation. Such surveys could explore whether firms engage in joint patenting, co-developed new products, or other forms of collaborative innovation, thereby offering a richer and more comprehensive perspective beyond patent records.

Moreover, this study focuses on firms' collaborative behavior in terms of international joint patent applications. In fact, digital trade rules that govern cross-border data flows may also enable firms to efficiently access, absorb, and integrate external knowledge, hence fostering their independent innovation efforts. Therefore, future research could further investigate how digital trade rules affect firms' independent innovation and the underlying mechanisms driving this effect.

CRediT authorship contribution statement

Bin Liu: Writing – original draft, Supervision, Methodology. **Chunmiao Liu:** Writing – original draft, Methodology, Data curation. **Chuanchuan Li:** Writing – original draft, Software, Methodology. **Xiao Chen:** Writing – review & editing, Writing – original draft, Project administration.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bin Liu reports financial support was provided by National Natural Science Foundation of China and University of International Business and Economics. Chuanchuan Li reports financial support was provided by Ministry of Education of China. Xiao Chen reports financial support was provided by National Natural Science Foundation of China. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Data and descriptive statistics

A.1. List of member countries of the Wassenaar arrangement

The Wassenaar Arrangement was established in 1996 following the dissolution of the Coordinating Committee for Export to Communist Countries and has since aimed to promote transparency and greater responsibility in transfers of conventional arms and dual-use goods and technologies. The Wassenaar Arrangement currently has 42 member countries. These include the 17 original members of the Coordinating Committee for Export to Communist Countries, namely Australia, Belgium, Canada, Denmark, France, Germany, Greece, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Turkey, the United Kingdom, and the United States. Additionally, it has 25 new members, namely Austria, Finland, Ireland, New Zealand, Sweden, Switzerland, Russia, the Czech Republic, Hungary, Poland, Slovakia, Argentina, South Korea, Romania, Bulgaria, Ukraine, and Slovenia (all of which joined by the end of 2004); Croatia, Estonia, Latvia, Lithuania, and Malta (all of which joined in early 2005); South Africa (which joined in late 2005); Mexico (which joined in late 2011), and India (which joined in 2017).

A.2. List of economies used in descriptive statistics

United Arab Emirates (AE), Argentina (AR), Austria (AT), Australia (AU), Bosnia and Herzegovina (BA), Barbados (BB), Belgium (BE), Bulgaria (BG), Bermuda (BM), Bolivia (BO), Brazil (BR), Canada (CA), Switzerland (CH), Chile (CL), China (CN), Colombia (CO), Costa Rica (CR), Cyprus (CY), Czech Republic (CZ), Germany (DE), Denmark (DK), Estonia (EE), Egypt (EG), Spain (ES), Finland (FI), France (FR), United Kingdom (GB), Gibraltar (GI), Greece (GR), Croatia (HR), Hungary (HU), Indonesia (ID), Ireland (IE), Israel (IL), India (IN), Italy (IT), Jamaica (JM), Jordan (JO), Japan (JP), Kenya (KE), South Korea (KR), Kuwait (KW), Cayman Islands (KY), Kazakhstan (KZ), Lebanon (LB), Liechtenstein (LI), Sri Lanka (LK), Liberia (LR), Lithuania (LT), Luxembourg (LU), Morocco (MA), Monaco (MC), Myanmar (MM), Malta (MT), Mauritius (MU), Mexico (MX), Malaysia (MY), Netherlands (NL), Norway (NO), New Zealand (NZ), Philippines (PH), Poland (PL), Portugal (PT), Paraguay (PY), Qatar (QA), Romania (RO), Serbia (RS), Russia (RU), Saudi Arabia (SA), Sudan (SD), Sweden (SE), Singapore (SG), Slovenia (SI), Slovakia (SK), Thailand (TH), Tunisia (TN), Turkey (TR), Ukraine (UA), Uganda (UG), United States (US), Venezuela (VE), British Virgin Islands (VG), Vietnam (VN), South Africa (ZA), Zambia (ZM), Zimbabwe (ZW), Bangladesh (BD), Bahamas (BS), Curaçao (CW), Guatemala (GT), Iran (IR), Latvia (LV), Nigeria (NG), Oman (OM), Panama (PA), Peru (PE), El Salvador (SV), and Uruguay (UY).

Appendix B. Construction of the patent monetary value range

To evaluate the monetary value generated for firms by the implementation of digital trade rules, we take the end of the sample period (i.e., the year 2020) as an example and use the average number of international joint patents in 2020 (i.e., 0.643) as the baseline to estimate the monetary gains associated with a 2.9 % increase in joint patents. For the monetary value of an individual patent, Giuri et al. (2007) report that about 68 % of patents are worth less than 1 million euros (in 2004 EUR), while Kogan et al. (2017) estimate the median patent value at 3.2 million US dollars (in 1982 USD). Given the variation in estimated patent value across studies, we adopt the former as a lower bound and the latter as an upper bound to construct a range of monetary value per patent.

To take currency conversion and inflation into account, we obtain the 2004 exchange rate between euros and US dollars (1 EUR = 1.244 USD), as well as the US Consumer Price Index (CPI) values for 1982 (96.533), 2004 (188.908), and 2020 (258.846). Using these data, we calculate the monetary value generated for firms by the implementation of digital trade rules in 2020. The calculation is as follows:

$$\text{Lower bound}: 1,000,000 \times 1.244 \times (258.846/188.908) \times 0.643 \times 0.029 = 31,785 \ \text{USD}$$

$$\text{Upper bound}: 3,200,000 \times (258.846/96.533) \times 0.643 \times 0.029 = 160,002 \ \text{USD}$$

Thus, we estimate that the implementation of digital trade rules enables firms to capture monetary value ranging from approximately 31,785 to 160,002 US dollars (in 2020 USD) through international joint patent applications.

Appendix C. Data used in robustness checks

C.1. List of countries with a patent box

Belgium (BE), Switzerland (CH), China (CN), Cyprus (CY), Spain (ES), France (FR), United Kingdom (GB), Greece (GR), Hungary (HU), Ireland (IE), Italy (IT), South Korea (KR), Liechtenstein (LI), Luxembourg (LU), Malta (MT), Netherlands (NL), Portugal (PT), and Turkey (TR).

C.2. List of tax havens

Andorra (AD), United Arab Emirates (AE), Antigua and Barbuda (AG), Anguilla (AI), Aruba (AW), Bahamas (BS), Bahrain (BH), Barbados (BB), Belize (BZ), Bermuda (BM), British Virgin Islands (VG), Cayman Islands (KY), Cook Islands (CK), Costa Rica (CR), Cyprus (CY), Dominica (DM), Djibouti (DJ), Gibraltar (GI), Grenada (GD), Guernsey (GG), Ireland (IE), Isle of Man (IM), Jersey (JE), Jordan (JO), Lebanon (LB), Liberia (LR), Liechtenstein (LI), Luxembourg (LU), Malta (MT), Marshall Islands (MH), Mauritius (MU), Micronesia (FM), Monaco (MC), Montserrat (MS), Nauru (NR), Netherlands Antilles (AN), Niue (NU), Panama (PA), Saint Kitts and Nevis (KN), Saint Lucia (LC), Saint Martin (MF), Saint Vincent and the Grenadines (VC), Samoa (WS), San Marino (SM), Seychelles (SC), Singapore (SG), Switzerland (CH), Tonga (TO), Turks and Caicos Islands (TC), and Vanuatu (VU).

Appendix D. Indicators used in the construction of digital trade provisions

TAPED database provides a comprehensive mapping of all digital trade-related provisions found in preferential trade agreements (PTAs) since

2000. As of November 2023, a total of 124 different items have been coded. These coded items cover five different areas such as ecommerce, data-dedicated provisions, new data economy issues, cross-cutting issues, and intellectual property. However, many items, especially those in cross-cutting issues, are about exceptions applicable to digital trade, which are less relevant to our research questions. And certain items in intellectual property are traditional intellectual property provisions rather than digital ones. Hence, we select some digital provisions closely related to digital trade from the TAPED database, rather than including all coded items.

Moreover, according to the WTO *E*-commerce Joint Statement Initiative (JSI), several fields are given special emphasis: (1) enabling digital trade (e.g., electronic transactions frameworks; electronic authentication and electronic signatures; electronic contracts; electronic invoicing; paperless trading); (2) trust and digital trade (e.g., data protection; cybersecurity; source code); (3) flow of information (e.g., cross-border data flows; location of computing facilities).

Therefore, given the varying functions of different digital trade provisions as well as JSI's classification, we reorganize these selected digital trade provisions and categorize them into four types, namely e-commerce (E-commerce), cross-border data flows (Flows), data protection (Protection), and digital intellectual property rights (IPR). These four types of provisions are set as four primary indicators, which are further divided into 12 secondary indicators and multiple specific provisions. To calculate the sub-index for digital trade provisions, we first average the scores of specific provisions under each secondary indicator to obtain the secondary indicator scores. We then average these secondary indicator scores to derive the primary indicator scores, and finally average the four primary indicators to measure the depth of digital trade rules. The construction of the indicators is specified in Table D.1.

Table D.1

Primary indicator	Secondary indicator	Specific provisions
E-commerce	Additional and deeper provisions of WTO rules	1.1.4. Does the agreement mention the applicability of WTO rules to e-commerce? 1.1.5. Does the agreement include provisions on transparency pertaining to e-commerce/digital trade? 1.4.1. Does the agreement include a provision on the non-imposition of customs duties on electronic transmissions? 1.4.2. Does the agreement include a provision on the customs value of carrier media?
	Principle of non-discriminatory treatment in e-commerce	1.1.3. Does the agreement include a principle of technological neutrality (i.e., apply the same treatment for digital supply)? 1.2.1. Does the agreement provide for national treatment (NT) in e-commerce/digital trade? 1.2.2. Does the agreement provide for most-favored-nation treatment in e-commerce/digital trade? 1.2.3. Are there services (and investment) market access and NT commitments for the sectors needed for e-commerce/digital trade?
	Digital trade facilitation provisions	1.5.1. Does the agreement include a provision on an electronic transactions framework? 1.5.2. Does the agreement include a provision on the consistency of the domestic legal framework with the United Nations Commission on International Trade Law Model Law on Electronic Commerce 1996? 1.5.3. Does the agreement include a provision on the consistency of the domestic legal framework with the United Nations Convection on the Use of Electronic Communications in International Contracts? 1.5.4. Does the agreement contain provisions on e-invoicing? 1.5.5. Does the agreement contain provisions on the facilitation of e-payments? 1.5.6. Does the agreement include provisions on electronic authentication, electronic signatures, or digital certificates? 1.6.1. Does the agreement include a provision on paperless trading? 1.6.2. Does the agreement contain a provision on electronic transferrable records? 1.6.3. Does the agreement contain a provision on customs procedure automatization or customs data exchange systems?
	Cooperation and dispute settlement	1.12.1. Does the agreement include an understanding on provisions about cooperation on information and communication technology, e-commerce, or digital trade? 1.14.1 Does the dispute settlement mechanism apply to e-commerce/digital trade provisions and, in particular, the core provisions on non-discrimination and customs duties?
Cross-border data flows	Free movement of data	2.2.1. Does the e-commerce/digital trade chapter include a provision on the free movement of data? 2.2.2. Does the e-commerce/digital trade chapter contain a mechanism to address barriers to data flows? 2.3.1. Does the agreement include a provision on the free movement of data outside the dedicated e-commerce/digital trade chapter? 2.3.2. Does the agreement include a mechanism to address barriers to data flows outside the dedicated e-commerce/digital trade chapter? 2.4.1. Is there any reference to the transfer of data or data flows in the telecommunications chapter/provisions? 2.4.2. Is there any reference to the transfer of data or data flows in the computer and related services chapter/provisions? 2.4.3. Is there any reference to the transfer of data or data flows in the audiovisual chapter/provisions? 2.4.4. Is there any reference to the transfer of data or data flows in the financial services chapter/provisions? 5.22. Does the agreement include provisions on data flows in the IP chapter?
	Non-localization of data	2.2.3. Does the e-commerce/digital trade chapter contain a provision banning or limiting data localization requirements? 2.3.3. Does the agreement include a provision banning or limiting data localization requirements outside the dedicated e-commerce/digital trade chapter?
Data protection	Data protection	2.1.1. Does the agreement include provisions on data protection? 2.1.2. Does the agreement include provisions on data protection with no qualifications? 2.1.3 Does the agreement include provisions on data protection according to domestic law? 2.1.4. Does the agreement include provisions on data protection recognizing certain key principles? 2.1.5. Does the agreement include provisions on data protection recognizing certain international standards? 2.1.6. Does the agreement include provisions on data protection as a least restrictive measure? 1.10.1. Does the agreement include provisions on cybersecurity?
Digital intellectual property rights	Digital copyright protection	5.1. Does the agreement adhere to the WIPO Internet Treaties? 5.15. Does the agreement include provisions on the liability of Internet service providers (ISPs)? 5.16. Does the agreement include provisions on safe harbors for ISPs?

(*continued on next page*)

Table D.1 (*continued*)

Primary indicator	Secondary indicator	Specific provisions
		5.19. Does the agreement include provisions on the right of reproduction in electronic form in copyright and related rights? 5.21. Does the agreement include provisions on storage of works of copyright and related rights in electronic form?
	Digital trademark protection	5.14. Does the agreement include provisions on Internet domain names?
	Digital patent and trade secret protection	5.11. Does the agreement include provisions on trade secrets or similar/like protection of undisclosed information/protection of data? 5.17. Does the agreement include provisions on patents for computer-implemented inventions (patents for software)?
	Digital technology protection	1.9.1. Does the agreement include prohibitions to require the transfer of, or access to, source code of software owned by a person, as a condition for the import, distribution, sale or use of such software? 1.9.2. Does the provision on source code make a separate reference to transfer of, or access to, an algorithm? 1.9.3. Does the agreement include provisions on cryptography? 1.9.4. Does the agreement include a provision on access to encrypted and/or unencrypted communications?
	Enforcement of digital intellectual property rights	5.9. Does the agreement include provisions on technological protection measures? 5.10. Does the agreement include provisions to protect information rights management?

Appendix E. Sectoral taxonomy of digital intensity

Calvino et al. (2018) provide a taxonomy of digital intensity sectors based on four dimensions of the digital transformation including: the share of tangible information and communication technology (ICT) and intangible (i.e., software) investment; the share of purchases of intermediate ICT goods and services; the stock of robots per hundreds of employees; the share of ICT specialists in total employment; and the share of turnover from online sales. For each considered dimension of the digital transformation, a sector's indicator-specific score is computed as a sector's position divided by 36 i. e., the total number of sectors included in the taxonomy. Then, these indicator-specific scores are then averaged across indicators, to yield one value per sector. Finally, they perform a quartile ranking of the 36 sectors based on their values i.e., Q1(High), Q2 (Medium-high), Q3 (Medium-low), Q4 (Low). The specific classification of sectors on digital intensity can be found in Table E.1.

Table E.1

Sector denomination	ISIC Rev.4	Quartile of digital intensity
Transport equipment	29–30	High
Telecommunications	61	High
IT and other information services	62–63	High
Finance and insurance	64–66	High
Legal and accounting activities, etc.	69–71	High
Scientific research and development	72	High
Advertising and market research; other business services	73–75	High
Administrative and support service activities	77–82	High
Other service activities	94–96	High
Wood and paper products, and printing	16–18	Medium-high
Computer, electronic and optical products	26	Medium-high
Electrical equipment	27	Medium-high
Machinery and equipment n.e.c.	28	Medium-high
Furniture; other manufacturing; repairs of computers	31–33	Medium-high
Wholesale and retail trade, repair	45–47	Medium-high
Publishing, audiovisual and broadcasting	58–60	Medium-high
Public administration and defence	84	Medium-high
Arts, entertainment and recreation	90–93	Medium-high
Textiles, wearing apparel, leather	13–15	Medium-low
Coke and refined petroleum products	19	Medium-low
Chemicals and chemical products	20	Medium-low
Pharmaceutical products	21	Medium-low
Rubber and plastics products	22–23	Medium-low
Basic metals and fabricated metal products	24–25	Medium-low
Education	85	Medium-low
Human health activities	86	Medium-low
Residential care and social work activities	87–88	Medium-low
Agriculture, forestry, fishing	01–03	Low
Mining and quarrying	05–09	Low
Food products, beverages and tobacco	10–12	Low
Electricity, gas, steam and air cond.	35	Low
Water supply; sewerage, waste management	36–39	Low
Construction	41–43	Low
Transportation and storage	49–53	Low
Accommodation and food service activities	55–56	Low
Real estate	68	Low

Data availability

Data will be made available on request.

References

Aghion, P., Bergeaud, A., Gigout, T., Lequien, M., Malitz, M., 2023. Exporting Ideas: Knowledge Flows from Expanding Trade in Goods. In: Center for Economic Performance Discussion Pap. No. 1960. London School of Economics and Political Science, London, UK. https://ideas.repec.org/p/cep/cepdps/dp1960.html.

Ahuja, G., 2000. The duality of collaboration: inducements and opportunities in the formation of interfirm linkages. Strateg. Manag. J. 21 (3–4), 317–343. https://doi.org/10.1002/(SICI)1097-0266(200003)21:3<317::AID-SMJ90>3.0.CO;2-B.

Arranz, N., de Arroyabe, J.C.F., 2008. The choice of partners in R&D cooperation: an empirical analysis of Spanish firms. Technovation 28 (1–2), 88–100. https://doi.org/10.1016/j.technovation.2007.07.006.

Arvanitis, S., Bolli, T., 2013. A comparison of national and international innovation cooperation in five European countries. Rev. Ind. Organ. 43, 163–191. https://doi.org/10.1007/s11151-012-9348-6.

Azmeh, S., Foster, C., Echavarri, J., 2020. The international trade regime and the quest for free digital trade. Int. Stud. Rev. 22 (3), 671–692. https://doi.org/10.1093/isr/viz033.

Bahar, D., Choudhury, P., Kim, D.Y., Koo, W.W., 2023. Innovation on wings: nonstop flights and firm innovation in the global context. Manag. Sci. 69 (10), 6202–6223. https://doi.org/10.1287/mnsc.2023.4682.

Barney, J., 1991. Firm resources and sustained competitive advantage. J. Manag. 17 (1), 99–120. https://doi.org/10.1177/014920639101700108.

Bayona, C., García-Marco, T., Huerta, E., 2001. Firms' motivations for cooperative R&D: an empirical analysis of Spanish firms. Res. Policy 30 (8), 1289–1307. https://doi.org/10.1016/S0048-7333 (00)00151-7.

Bönte, W., Keilbach, M., 2005. Concubinage or marriage? Informal and formal cooperations for innovation. Int. J. Ind. Organ. 23 (3–4), 279–302. https://doi.org/10.1016/j.ijindorg.2005.01.007.

Bottazzi, L., Peri, G., 2003. Innovation and spillovers in regions: evidence from European patent data. Eur. Econ. Rev. 47 (4), 687–710. https://doi.org/10.1016/S0014-2921(02)00307-0.

Breschi, S., Lissoni, F., 2001. Knowledge spillovers and local innovation systems: a critical survey. Ind. Corp. Chang. 10 (4), 975–1005. https://doi.org/10.1093/icc/10.4.975.

Briggs, K., 2015. Co-owner relationships conducive to high quality joint patents. Res. Policy 44 (8), 1566–1573. https://doi.org/10.1016/j.respol.2015.05.011.

Brockman, P., Khurana, I.K., Zhong, R.I., 2018. Societal trust and open innovation. Res. Policy 47 (10), 2048–2065. https://doi.org/10.1016/j.respol.2018.07.010.

Broekel, T., 2019. Using structural diversity to measure the complexity of technologies. PLoS One 14 (5), e0216856. https://doi.org/10.1371/journal.pone.0216856.

Burri, M., Polanco, R., 2020. Digital trade provisions in preferential trade agreements: introducing a new dataset. J. Int. Econ. Law 23 (1), 187–220. https://doi.org/10.1093/jiel/jgz044.

Business Software Alliance, 2017. Cross-border data flows. https://www.bsa.org/policy-filings/cross-border-data-flows.

Calvino, F., Criscuolo, C., Marcolin, L., Squicciarini, M., 2018. A Taxonomy of Digital Intensive Sectors. In: OECD Sci. Technol. Ind. Work. Pap. No. 2018/14. OECD Publishing, Paris. https://doi.org/10.1787/f404736a-en.

Cassiman, B., Veugelers, R., 2002. R&D cooperation and spillovers: some empirical evidence from Belgium. Am. Econ. Rev. 92 (4), 1169–1184. https://doi.org/10.1257/00028280260344704.

Chander, A., Lê, U.P., 2015. Data nationalism. Emory Law J. 64 (3), 677–740. https://scholarlycommons.law.emory.edu/elj/vol64/iss3/2/.

Choi, C.B., Beamish, P.W., 2013. Resource complementarity and international joint venture performance in Korea. Asia Pac. J. Manag. 30, 561–576. https://doi.org/10.1007/s10490-011-9258-4.

Cinelli, C., Forney, A., Pearl, J., 2024. A crash course in good and bad controls. Sociol. Methods Res. 53 (3), 1071–1104. https://doi.org/10.1177/00491241221099552.

Cory, N., 2019. The False Appeal of Data Nationalism: Why the Value of Data Comes from How It's Used, Not Where It's Stored. ITIF. https://itif.org/publications/2019/04/01/false-appeal-data-nationalism-why-value-data-comes-how-its-used-not-where/.

Cory, N., Dascoli, L., 2021. How Barriers to Cross-Border Data Flows Are Spreading Globally, What They Cost, and How to Address Them. ITIF. https://itif.org/publications/2021/07/19/how-barriers-cross-border-data-flows-are-spreading-globally-what-they-cost/.

Das, T.K., Teng, B.S., 2000. A resource-based theory of strategic alliances. J. Manag. 26 (1), 31–61. https://doi.org/10.1177/014920630002600105.

Dodgson, M., 1992. The strategic management of R&D collaboration. Tech. Anal. Strat. Manag. 4 (3), 227–244. https://doi.org/10.1080/09537329208524096.

Faraj, S., Jarvenpaa, S.L., Majchrzak, A., 2011. Knowledge collaboration in online communities. Organ. Sci. 22 (5), 1224–1239. https://doi.org/10.1287/orsc.1100.0614.

Feldman, M.P., Kogler, D.F., 2010. Stylized facts in the geography of innovation. In: Handb. Econ. Innov., 1, pp. 381–410. https://doi.org/10.1016/S0169-7218(10)01008-7.

Ferencz, J., 2019. The OECD Digital Services Trade Restrictiveness Index. In: OECD Trade Policy Pap. No. 221. OECD Publishing, Paris. https://doi.org/10.1787/16ed2d78-en.

Ferracane, M.F., van der Marel, E., 2023. Digital Trade Regulatory Environment: Opportunities for Regulatory Harmonization in Africa. UN Econ. Comm. Afr. African Trade Policy Centre (ATPC) Rep. [Global Governance Programme]. https://hdl.handle.net/1814/75946.

Forge, F., Garred, J., Kwon, K.L., 2024. When are tariff cuts not enough? Heterogeneous effects of trade preferences for the least developed countries. J. Int. Econ., 103971 https://doi.org/10.1016/j.jinteco.2024.103971.

Fritz, J., Giardini, T., 2023. Data governance regulation in the G20: a systematic comparison of rules and their effect on digital fragmentation. File:///D:/1699349399931_Report%20-%20Fragmentation%20risk%20from%20data%20governance%20regulation%20-%20Final%20.Pdf.

Froese, M.D., 2019. Digital trade and dispute settlement in RTAs: an evolving standard? J. World Trade 53 (5), 783–809. https://doi.org/10.54648/trad2019031.

Fu, X., Fu, X.M., Ghauri, P., Hou, J., 2022. International collaboration and innovation: evidence from a leading Chinese multinational enterprise. J. World Bus. 5 (4), 101329. https://doi.org/10.1016/j.jwb.2022.101329.

Ganguli, I., 2015. Immigration and ideas: what did Russian scientists "bring" to the United States? J. Labor Econ. 33 (S1), S257–S288. https://doi.org/10.1086/679741.

Giuri, P., Mariani, M., Brusoni, S., Crespi, G., Francoz, D., Gambardella, A., Garcia-Fontes, W., Geuna, A., Gonzales, R., Harhoff, D., Hoisl, K., 2007. Inventors and invention processes in Europe: results from the PatVal-EU survey. Res. Policy 36 (8), 1107–1127. https://doi.org/10.1016/j.respol.2007.07.008.

Global Data Alliance, 2021a. Cross-border data transfers & innovation. https://globaldataalliance.org/wp-content/uploads/2021/07/04012021cbdtinnovation.pdf.

Global Data Alliance, 2021b. Cross-border data transfers & biopharmaceutical research and development. https://globaldataalliance.org/wp-content/uploads/2021/09/09092021cbdtbiopharma.pdf.

Gorbatyuk, A., Van Overwalle, G., Van Zimmeren, E., 2016. Intellectual property ownership in coupled open innovation processes. IIC-Int. Rev. Intellect. Prop. Compet. Law 47, 262–302. https://doi.org/10.1007/s40319-016-0461-1.

Guellec, D., Paunov, C., 2018. Innovation Policies in the Digital Age. In: OECD Sci. Technol. Ind. Policy Pap. No. 59. OECD Publishing, Paris. https://doi.org/10.1787/eadd1094-en.

Guellec, D., van Pottelsberghe de la Potterie, B., 2001. The internationalisation of technology analysis with patent data. Res. Policy 30 (8), 1253–1266. https://doi.org/10.1016/S0048-7333 (00)00149-9.

Hagedoorn, J., 1993. Understanding the rationale of strategic technology partnering: Interorganizational modes of cooperation and sectoral differences. Strateg. Manag. J. 14 (5), 371–385. https://doi.org/10.1002/smj.4250140505.

Hagedoorn, J., Kranenburg, H.V., Osborn, R.N., 2003. Joint patenting amongst companies–exploring the effects of inter-firm R&d partnering and experience. Manag. Decis. Econ. 24 (2–3), 71–84. https://doi.org/10.1002/mde.1078.

Hagedoorn, J., Cloodt, D., Van Kranenburg, H., 2005. Intellectual property rights and the governance of international R&D partnerships. J. Int. Bus. Stud. 36, 175–186. https://doi.org/10.1057/palgrave.jibs.8400122.

Hashimoto, T., Tanaka, Y., Adrian, A., 2012. Managing joint R&D: an investigation into joint patent applications in Japan, USA, and Europe. Int. J. Technol. Transf. Commer. 11 (3–4), 137–155. https://doi.org/10.1504/IJTTC.2012.052420.

Haskel, J.E., Pereira, S.C., Slaughter, M.J., 2007. Does inward foreign direct investment boost the productivity of domestic firms? Rev. Econ. Stat. 89 (3), 482–496. https://doi.org/10.1162/rest.89.3.482.

Hegde, D., Herkenhoff, K., Zhu, C., 2023. Patent publication and innovation. J. Polit. Econ. 131 (7), 1845–1903. https://doi.org/10.1086/723636.

Heiman, B.A., Nickerson, J.A., 2004. Empirical evidence regarding the tension between knowledge sharing and knowledge expropriation in collaborations. Manag. Decis. Econ. 25 (6–7), 401–420. https://doi.org/10.1002/mde.1198.

Herman, P.R., Oliver, S., 2023. Trade, policy, and economic development in the digital economy. J. Dev. Econ. 164, 103135. https://doi.org/10.1016/j.jdeveco.2023.103135.

Hines Jr., J.R., 2010. Treasure islands. J. Econ. Perspect. 24 (4), 103–126. https://doi.org/10.1257/jep.24.4.103.

Hsu, D.H., Hsu, P.H., Zhou, K., Zhou, T., 2025. Industry-university collaboration and commercializing Chinese corporate innovation. Manag. Sci. 71 (6), 5351–5375. https://doi.org/10.1287/mnsc.2022.00788.

Jaffe, A.B., Trajtenberg, M., 1999. International knowledge flows: evidence from patent citations. Econ. Innov. New Technol. 8 (1–2), 105–136. https://doi.org/10.1080/10438599900000006.

Jaffe, A.B., Trajtenberg, M., Henderson, R., 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. Q. J. Econ. 108 (3), 577–598. https://doi.org/10.2307/2118401.

Jinji, N., Zhang, X., Haruna, S., 2019. Do deeper regional trade agreements enhance international technology spillovers? World Econ. 42 (8), 2326–2363. https://doi.org/10.1111/twec.12797.

Keller, W., 2004. International technology diffusion. J. Econ. Lit. 42 (3), 752–782. https://doi.org/10.1257/0022051042177685.

Keller, W., Yeaple, S.R., 2009. Multinational enterprises, international trade, and productivity growth: firm-level evidence from the United States. Rev. Econ. Stat. 91 (4), 821–831. https://doi.org/10.1162/rest.91.4.821.

Keller, W., Yeaple, S.R., 2013. The gravity of knowledge. Am. Econ. Rev. 103 (4), 1414–1444. https://doi.org/10.1257/aer.103.4.1414.

Kim, C., Song, J., 2007. Creating new technology through alliances: an empirical investigation of joint patents. Technovation 27 (8), 461–470. https://doi.org/10.1016/j.technovation.2007.02.007.

Kogan, L., Papanikolaou, D., Seru, A., Stoffman, N., 2017. Technological innovation, resource allocation, and growth. Q. J. Econ. 132 (2), 665–712. https://doi.org/10.1093/qje/qjw040.

Lanjouw, J.O., Schankerman, M., 2004. Patent quality and research productivity: measuring innovation with multiple indicators. Econ. J. 114 (495), 441–465. https://doi.org/10.1111/j.1468-0297.2004.00216.x.
Laursen, K., Salter, A.J., 2014. The paradox of openness: appropriability, external search and collaboration. Res. Policy 43 (5), 867–878. https://doi.org/10.1016/j.respol.2013.10.004.
Lhuillery, S., Pfister, E., 2009. R&D cooperation and failures in innovation projects: empirical evidence from French CIS data. Res. Policy 38 (1), 45–57. https://doi.org/10.1016/j.respol.2008.09.002.
Liu, Q., Ma, H., 2020. Trade policy uncertainty and innovation: firm level evidence from China's WTO accession. J. Int. Econ. 127, 103387. https://doi.org/10.1016/j.jinteco.2020.103387.
López González, J., Sorescu, S., Kaynak, P., 2023. Of Bytes and Trade: Quantifying The Impact of Digitalisation on Trade. In: OECD Trade Policy Pap. No. 273. OECD Publishing, Paris. https://doi.org/10.1787/11889f2a-en.
Ma, S., Shen, Y., Fang, C., 2024. Can data flow provisions facilitate trade in goods and services?—analysis based on the TAPED database. J. Int. Trade Econ. Dev. 33 (3), 343–368. https://doi.org/10.1080/09638199.2023.2179860.
MacKinnon, J.G., Magee, L., 1990. Transforming the dependent variable in regression models. Int. Econ. Rev. 31 (2), 315–339. https://doi.org/10.2307/2526842.
Mariti, P., Smiley, R.H., 1983. Co-operative agreements and the organization of industry. J. Ind. Econ. 31 (4), 437–451. https://doi.org/10.2307/2098340.
Martínez-Zarzoso, I., Arregui Coka, D., 2025. Do trade agreements contribute to technology internationalization? J. Int. Trade Econ. Dev. 34 (7), 1–43. https://doi.org/10.1080/09638199.2025.2482549.
Miotti, L., Sachwald, F., 2003. Co-operative R&D: why and with whom?: an integrated framework of analysis. Res. Policy 32 (8), 1481–1499. https://doi.org/10.1016/S0048-7333 (02)00159-2.
Neri-Lainé, M., Orefice, G., Ruta, M., 2023. Deep Trade Agreements and Heterogeneous Firms Exports. In: CESifo Work. Pap. No. 10436. Center for Economic Studies and ifo Institute, Munich. https://doi.org/10.2139/ssrn.4459813.
Nisar, T.M., Prabhakar, G., Strakova, L., 2019. Social media information benefits, knowledge management and smart organizations. J. Bus. Res. 94, 264–272. https://doi.org/10.1016/j.jbusres.2018.05.005.
Oxley, J.E., 1999. Institutional environment and the mechanisms of governance: the impact of intellectual property protection on the structure of inter-firm alliances. J. Econ. Behav. Organ. 38 (3), 283–309. https://doi.org/10.1016/S0167-2681 (99)00011-6.
Peri, G., 2005. Determinants of knowledge flows and their effect on innovation. Rev. Econ. Stat. 87 (2), 308–322. https://doi.org/10.1162/0034653053970258.
Peteraf, M.A., 1993. The cornerstones of competitive advantage: a resource-based view. Strateg. Manag. J. 14 (3), 179–191. https://doi.org/10.1002/smj.4250140303.
Picci, L., 2010. The internationalization of inventive activity: a gravity model using patent data. Res. Policy 39 (8), 1070–1081. https://doi.org/10.1016/j.respol.2010.05.007.
Robin, S., Schubert, T., 2013. Cooperation with public research institutions and success in innovation: evidence from France and Germany. Res. Policy 42 (1), 149–166. https://doi.org/10.1016/j.respol.2012.06.002.
Sakakibara, M., 1997. Heterogeneity of firm capabilities and cooperative research and development: an empirical examination of motives. Strateg. Manag. J. 18 (S1), 143–164. https://doi.org/10.1002/(SICI)1097-0266 (199707)18:1+<143::AID-SMJ927>3.0.CO;2-Y.
Słok-Wódkowska, M., Mazur, J., 2022. Secrecy by default: how regional trade agreements reshape protection of source code. J. Int. Econ. Law 25 (1), 91–109. https://doi.org/10.1093/jiel/jgac005.
Spiezia, V., Tscheke, J., 2020. International Agreements on Cross-Border Data Flows and International Trade: A statistical analysis. In: OECD Sci. Technol. Ind. Work. Pap. No. 2020/09. OECD Publishing, Paris. https://doi.org/10.1787/b9be6cbf-en.
Srholec, M., 2015. Understanding the diversity of cooperation on innovation across countries: multilevel evidence from Europe. Econ. Innov. New Technol. 24 (1–2), 159–182. https://doi.org/10.1080/10438599.2014.897864.
Suh, J., Roh, J., 2023. The effects of digital trade policies on digital trade. The World Econ. 46 (8), 2383–2407. https://doi.org/10.1111/twec.13407.
Suh, J., Lee, J., Roh, J., 2024. On the non-discrimination principles in digital trade. World Trade Rev. 23 (1), 72–92. https://doi.org/10.1017/S147474562300037X.
Tenzer, H., Pudelko, M., Zellmer-Bruhn, M., 2021. The impact of language barriers on knowledge processing in multinational teams. J. World Bus. 56 (2), 101184. https://doi.org/10.1016/j.jwb.2020.101184.
von Zedtwitz, M., Gassmann, O., 2002. Market versus technology drive in R&D internationalization: four different patterns of managing research and development. Res. Policy 31 (4), 569–588. https://doi.org/10.1016/S0048-7333 (01)00125-1.
Wernerfelt, B., 1984. A resource-based view of the firm. Strateg. Manag. J. 5 (2), 171–180. https://doi.org/10.1002/smj.4250050207.
World Economic Forum, 2016. Cross-border data flows, digital innovation, and economic growth. https://www3.weforum.org/docs/GITR2016/WEF_GITR_Chapter1.2_2016.pdf.
World Economic Forum, 2020. A roadmap for cross-border data flows: future-proofing. https://www3.weforum.org/docs/WEF_A_Roadmap_for_Cross_Border_Data_Flows_2020.pdf.
Wu, J., Luo, Z., Wood, J., 2023. How do digital trade rules affect global value chain trade in services?—analysis of preferential trade agreements. World Econ. 46 (10), 3026–3047. https://doi.org/10.1111/twec.13412.