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Import spillovers and innovation efficiency: the role of intellectual property protection in China

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ABSTRACT

This paper examines how import spillovers affect innovation efficiency across different innovation contexts in China by using a Chinese regional panel dataset from 2001 to 2020. The results indicate the coexistent of two opposing mechanisms of import spillovers: learning effects and adverse crowd-out effects. The import spillovers positively affect R&D efficiency and IPR protection positively moderates the relationship between import spillovers and R&D efficiency. Moreover, IPR and R&D efficiency present an inverted U-shaped relationship. By contrast, import spillovers negatively affect commercialization efficiency and IPR protection negatively moderates the relationship between import spillovers and commercialization efficiency. There is significant heterogeneity impact in different regions. These findings contribute to understanding the impact of IPR protection on innovation in emerging markets.

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1. Introduction

Since 2012, China has established itself as the world's second-largest importer. By 2018, the total volume of the nation's foreign trade had surged to 30.51 trillion yuan, with imports accounting for 14.09 trillion yuan – representing a year-on-year increase of 12.9%, as documented in the World Integrated Trade Solution (WITS) database.

As evidenced by previous studies (Coe, Helpman, and Hoffmaister 2009; J. W. Kim and Lee 2004), technological knowledge is inherently embodied within imported goods. However, the reliance on labor endowments to integrate into the lower tiers of global value chains (GVCs), orchestrated by developed nations, has inevitably fostered substantial dependence on foreign imports for critical equipment and components. The increase of China's imports has prompted both scholars and practitioners to ponder if, and how local firms can benefit from the imports spillovers.

Despite the large amount of literature on the impact of imports on innovation, empirical conclusions remain inconsistent. Whereas some studies have identified positive

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spillover effects (Parameswaran 2009), others have shown that import spillovers exert negative impact (Q. Liu and Qiu 2016b). We believe that the controversy may be partially attributed to divergence in the measurements of innovation. The majority of research on spillovers is conducted at the macro level, focusing on innovation inputs (Zhao 2021) or productivity (Coe, Helpman, and Hoffmaister 2009). Innovation efficiency, defined as the relative capability to maximize innovation outputs given a certain quantity of innovation inputs (Cruz-Cázares, Bayona-Sáez, and García-Marco 2013), has been underexplored. Although extant studies provide critical insights into the innovation performance, there remain limits. From the perspective of the innovation value chain, innovation is a complex process encompassing both the knowledge creation phase and the commercialization phase. To fill this gap, this study decomposes innovation efficiency into R&D efficiency and commercialization efficiency and subsequently investigates the impact of import spillovers on these two dimensions.

The moderating role of intellectual property rights (IPR) enforcement was considered in the study. Innovation in developing economies is contingent upon appropriate institutional arrangement. Prior study has analyzed the impact of import spillovers on China's innovation and the varying influence of IPR protection from different lenses (R. Zhou et al. 2019). Sharma, Sousa, and Woodward (2022) highlights the institutional quality is a significant determinant of innovation performance. Although previous studies have emphasized the impact of IPR protection on patents, they have largely overlooked its role in the commercialization of innovation. We identified the moderating role of IPR protection strength in the relationship between import spillovers and regional commercialization efficiency. We further conducted empirical tests to ascertain whether a non-monotonic relationship exists between IPR strength and innovation.

This study aims to address the following three questions. (1) Do import spillovers positively influence innovation efficiency, specially regarding both R&D efficiency and commercialization efficiency. (2) How dose IPR protection moderate the relationship between the import spillovers and innovation efficiency? (3) Are there regional heterogeneities in the impact of import spillovers on R&D efficiency and commercialization efficiency?

This rest of the study is organized as follows. Section 2 reviews the related literature. Section 3 discusses data, models, and methodologies. Section 4 presents the empirical results. Finally, we present the discussions and conclusions.

2. Related literature

2.1. Innovation and R&D spillovers

This research relates to at least two streams of the relevant literature. The first strand has investigated the relationship between innovation and import spillovers.

Imports are an important transmission channel of foreign know-how. A huge amount of foreign knowledge is inadvertently transmitted via the import of machinery and capital goods. Building upon the seminal analysis by Coe and Helpman (1995), the majority of empirical investigations have concluded that import spillovers are localized and trade-related. Trade can exert an influence on Total Factor Productivity (TFP) via import spillovers (Belitz and Moelders 2016; Coe, Helpman, and Hoffmaister 2009; Fracasso and Vittucci Marzetti 2015; Krammer 2010; Lichtenberg and van Pottelsberghe 1998). Notably, Lichtenberg and van Pottelsberghe (1998) re-evaluated the econometric model of Coe and Helpman (1995) with imports weighted by the GDP of the trade partner that is much less biased theoretically. Krammer (2010) provides evidence that imports constitute the main channel for the transmission of international knowledge from more advanced nations to the relatively less developed countries. Existing studies show that a nation's absorptive capacity is positively related to foreign R&D spillovers (Coe, Helpman, and Hoffmaister 2009; Engelbrecht 1997; Fracasso and Vittucci Marzetti 2014). Indeed, the realization of international R&D spillovers depends on the recipient country's capability to assimilate and utilize external knowledge (Massini, Piscitello, and Shevtsova 2023; Schiff and Wang 2017). Davis and Aggarwal (2020) reveal that threshold of absorptive capacity is critical in capturing the knowledge spillover at the firm-level. Coe, Helpman, and Hoffmaister (2009) identify that institutional disparities also significantly influence TFP and the magnitude of R&D spillovers. Kekezi, Dall'erba, and Kang (2022) underscore the sectoral heterogeneity in the size of the localized knowledge spillovers from university research. Qian, Hong, Hou, et al. (2022) analyze the effects of three technology transfer channels – namely foreign technology import, global value chain participation and domestic technology purchase on innovation efficiency within China's manufacturing industries. The findings indicate that both foreign technology import and global value chain participation act as catalysts for innovation efficiency.

Some scholars argue that imports have different impact on innovation. Q. Liu and Qiu (2016a) in their examination of how tariff declines of intermediate inputs affect the innovation activities of local firms reveal that the import of high-quality inputs induces a substitution effect regarding the innovation of Chinese enterprises. Goel (2022) argued that high-tech imports crowd out innovation, whereas increased imports of ICT products enhance it. J. Liu, Lu, and Cheng (2018) demonstrate that while foreign R&D spillovers positively bolster the production of scientific papers, they simultaneously inhibit the innovation efficiency of domestic patents through Stochastic Frontier Analysis (SFA) analysis. Table 1 summarizes the different relationship between R&D spillovers and innovation.

Despite the substantial contribution of prior research, there is no clear consensus on the relationship between innovation and import spillovers. Some shortcomings remain: (1) The measurement of efficiency is mostly confined to macro- and industry-level analyses. (2) While extant studies present frontier innovation driven by R&D investment, they have ignored market-driven commercialization innovation.

In this paper, this paper focuses on the innovation process from the perspective of innovation value chain at provincial level. Specially, we directly explore the impact of international R&D spillovers on both R&D efficiency and commercialization efficiency, systematically investigating the impact of import spillovers on them.

Table 1. The linkage between R&D spillovers and innovation.

Author(s)	Sample	Relationship	Measurement of innovation
Coe and Helpman (1995)	21 OECD countries	Positive	TFP
Liu and Buck (2007)	Hi-tech industry in China	Positive	new product sales per employee of local Chinese firms
Coe, Helpman, and Hoffmaister (2009)	24 countries	Positive	TFP
Belitz and Moelders (2016)	OECD countries	Positive	TFP
J. Liu, Lu, and Cheng (2018)	44 countries	Mixed effect	innovation efficiency
Q. Liu and Qiu (2016a)	Chinese firm-level data	Negative	the number of patents filed by a firm
Kekezi, Dall'erba, and Kang (2022)	five US manufacturing sectors and 853 metropolitan counties	Positive	patent application
Massini, Piscitello, and Shevtsova (2023)	multinational enterprises	Positive	TFP
Goel (2022)	131countries	Mixed effect	number of resident patent applications/ number of patent cooperation treaty
Qian, Hong, Hou, et al. (2022)	manufacturing industries in China	Positive	innovation efficiency

2.2. Intellectual property rights and innovation

The second stream of literature includes empirical studies on the effects of IPR protection and innovation. The relationship between the protection of IPR and innovation has long been a subject of scholarly debate.

A body of empirical research posits that stronger IPR protection enhances innovation (Allred and Park 2007; Di Vita 2017; Sunil and Robert 2003). Coe, Helpman, and Hoffmaister (2009) demonstrate that stringent patent protection facilitates the TFP and amplifies the degree of international R&D spillovers. Y. Chen and Puttitanun (2005) argue that innovation in developing countries exhibits a positive correlation with the degree of IPR protection, while also emphasizing that a country's optimal IPR regime depends on its stage of economic development.

Conversely, some have also acknowledged the negative impacts of implementing strong IPR protection (Gangopadhyay and Mondal 2012; Helpman 1993; Sharma, Sousa, and Woodward 2022). Helpman (1993) argues that while the rate of innovation may increase in the short run with strong IPR, it may subsequently decline over the long term. The tightening of IPR impedes technology diffusion to developing countries by raising costs and undermining the terms of trade between these nations and the more developed ones. Moreover, strong IPR may adversely affect innovation by limiting the possibility of learning through imitation (Auriol, Biancini, and Paillacar 2023; Goldberg et al. 2008). Excessively strict patent protection may hinder sequential and complementary innovation within complex industries by constraining knowledge flows, owing to the propensity of such protection to restrict the disclosure of the details of invention details in patent applications (Bessen and Maskin 2009; Woo, Jang, and Kim 2015).

The non-linear relationship between IPR strength and innovation performance has been examined because of the different effects (Allred and Park 2007; Hudson and Minea 2013;

Sharma, Sousa, and Woodward 2022). Hudson and Minea (2013) point out that countries with comparable level of IPR protection may have significantly different innovation effects, attributable to variations in their levels of economic development. Different levels of IPR protection may be needed to maximize technological 'catch-up' (Acha, Marsili, and Nelson 2004; Y. K. Kim et al. 2012).

Our study is also associated with the literature on IPR enforcement. The efficacy of IPR protection is not solely contingent upon patent-related legislation but is also profoundly influenced by the extent of IPR law enforcement. Ostergard (2000) categorizes IPR laws into three types and quantifies their respective enforcement components. Papageorgiadis, Cross, and Alexiou (2014) developed a composite index to assess the international patent systems strength, with an emphasis on the enforcement aspects at the national level. Many scholars have examined the impact of IPR protection in China, employing diverse measurements. The ratio of technology transfer transaction volume to regional GDP has been widely used as a proxy for regional IPR protection (Ang, Cheng, and Wu 2014; Hou et al. 2023; W. C. Zhou and Wang 2020). Sun et al. (2017) measure region-specific IPR enforcement by using the ratio of the total number of IPR cases to the number of settled IPR cases in a given region. Fang, Lerner, and Wu (2016) uses a survey-based IPR index at provincial level within China, which yielding different outcomes. Wan et al. (2021) analyze the effects of IPR protection on innovation efficiency using 30 hi-tech industries. The main studies are presented in Table 2.

Since the beginning of China's reform and opening-up policy, economic development and innovation capabilities have been unevenly distributed across regions (Hou et al. 2023). Prior research has examined the effects of IPR on innovation at the national level or firm level, with a focus on innovation output or productivity. Nevertheless, there remain limits in exploring whether regional heterogeneity influences the impact of IPR enforcement on innovation efficiency. We have

Table 2. The linkage between ipr and innovation.

Author(s)	Sample	Relationship between IPR and innovation	Measurement of IPR
Y. Chen and Puttitanun (2005)	64 developing countries	positive	GP index
Auriol, Biancini, and Paillacar (2023)	112 countries	negative	GP index
Hudson and Minea (2013)	62countries	U-shaped	GP index
Ang, Cheng, and Wu (2014)	Hi-tech firms of China	positive	IPR enforcement
Allred and Park (2007)	Country-level and firm-level data	U-shaped in developed countries Inverted-U in developing countries	GP index
Woo, Jang, and Kim (2015)	12 countries and 3 industries	negative	GP index
Sharma, Sousa, and Woodward (2022)	50 countries	Inverted-U shaped	IPR enforcement
Sweet and Sacha Eterovic Maggio (2015)	94 countries	positive	GP index
W. C. Zhou and Wang (2020)	Listed firms in China	positive	IPR reform or reversal
Wan et al. (2021)	Hi-tech industry in China	Positive	IPR enforcement
J. Chen and Zhou (2023)	31provinces	Positive	IPR enforcement

developed a novel composite index of IPR protection and investigated how import spillovers influence innovation efficiency through differing regional IPR protection. The non-linear relationship between IPR protection and innovation is also tested.

3. Methodology and data

3.1. Methodology

We have decomposed innovation efficiency into R&D efficiency and commercialization efficiency from the perspective of innovation value chain. Subsequently, we estimated the drivers of the two stage independently.

The CH model, proposed by Coe and Helpman (1995), has been extensively applied to estimate the effects of international R&D spillovers on TFP. Analogous to the CH model, our basic econometric model is specified as follows:

$$\ln \Delta Y_{it} = \alpha_0 + \beta_1 \ln S_{it}^f + \beta_2 \ln IPR_{it} + \varepsilon_{it} \tag{1}$$

where ΔY represents R&D efficiency and commercialization efficiency, respectively. S^f denotes the foreign R&D capital stock. ε is a random error term. IPR is the strength of IPR protection. i and t denote regions of China (1 . . . , 30) and time (years), respectively.

We use RE and CE to represent R&D efficiency and commercialization efficiency in the following equations:

$$\ln \mathrm{RE}_{it} = \alpha_0 + \beta_1 \ln \ln S_{it}^f + \beta_2 \ln IPR_{it} + \varepsilon_{it} \tag{2}$$

$$\ln \mathrm{CE}_{it} = \alpha_0 + \beta_1 \ln S_{it}^f + \beta_2 \ln IPR_{it} + \varepsilon_{it} \tag{3}$$

We are most interested in the impact of the protection of IPR on the variation of R&D spillovers to R&D efficiency and commercialization efficiency, respectively. We constructed an interaction term of international R&D spillovers and IPR protection. Lastly, the IPR squared term tests whether a non-linear relationship exists between IPR protection and innovation efficiency. The specification is as follows:

$$\begin{aligned} \mathrm{ln}\Delta \mathrm{Y}_{\mathrm{it}} = {} & \alpha_0 + \beta_1 \mathrm{lnS}_{\mathrm{it}}^{\mathrm{f}} + \beta_2 \mathrm{lnIPR}_{\mathrm{it}} + \beta_3 \mathrm{lnS}_{\mathrm{it}}^{\mathrm{f}} * \mathrm{lnIPR}_{\mathrm{it}} + \beta_4 (\mathrm{lnIPR}_{\mathrm{it}})^2 \\ & + \beta_5 \mathrm{X}_{\mathrm{it}} + \omega_{\mathrm{i}} + \delta_{\mathrm{t}} + \varepsilon_{\mathrm{it}} \end{aligned} \tag{4}$$

where X is a matrix of control variables, regional fixed effect ω_i, time fixed effect δ_t, and error term ε_{it} are included.

3.2. The variables

3.2.1. Dependent variable

Malmquist DEA can handle multiple inputs and outputs simultaneously when DMUs are repeatedly observed between two periods of time (Z. Li, Crook, and Andreeva 2017). We use this method to examine time series changes in innovation efficiency at the regional level.

We assume production technology S^t which can produce outputs vectors, $y^t \in R_+^M$, with the inputs vectors, $x^t \in R_+^N$ during period t.

The output distance function refers to the inverse of the 'maximum' proportional expansion of the outputs y^t at t, given inputs x^t.

$$D_0^t(x^t, y^t) = \inf\{\theta : (x^t, y^t/\theta) \in S^t\} = \left(\sup\{\theta : (x^t, \theta y^t) \in S^t\}\right)^{-1} \tag{5}$$

$D_0^t(x^t, y^t) \leq 1$ if and only if $(x^t, y^t) \in S^t . D_0^t(x^t, y^t) = 1$ if and only if (x^t, y^t) is at the frontier of technology.

The Malmquist productivity index of the production point (x^{t+1}, y^{t+1}) relative to the production point (x^t, y^t) is given as follows:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\right)\left(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right)\right]^{1/2} \tag{6}$$

where $D_0^t(x^{t+1}, y^{t+1})$ and $D_0^{t+1}(x^t, y^t)$ are distance functions. The former measures the maximal proportional change in outputs required to make (x^{t+1}, y^{t+1}) feasible with the reference technology at t. The latter is computed analogously in terms of the reference technology at $t+1$ (Fare et al. 1994).

Equation (2) can be rewritten as:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{1/2} \tag{7}$$

where efficiency improvement (EC) and technical change (TC) are

$\mathrm{EC} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}$ and

$$\mathrm{TC} = \left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{1/2}$$

In contrast to traditional measurement such as TFP, the concept of innovation efficiency is related to productivity, the aim of which is to maximise outputs given a certain amount of R&D inputs (Y. Chen 2011; Cruz-Cazares, Bayona-Saez, and Garcia-Marco 2013; Hashimoto and Haneda 2008; Yi and Peng 2018). The Malmquist index methodology can be used to examine time series changes in innovation efficiency. Furthermore, innovation efficiency can be divided into two sequential phases: the R&D phase and the commercialization phase. This segmentation proves instrumental in distinguishing the different effects of international R&D spillovers on the process of technological advancement and technological conversion.

Drawing on previous research, the full-time equivalent of R&D personnel and intramural R&D expenditure are selected as the two principal inputs variables (Qian, Hong, Fang, et al. 2022). Since invention patents represent the level of new technological research and development. The number of invention patent applications is employed as the output indicator for the first stage. Some alternative indicators of innovation output are also used. These include profits, sales, and new products (Cruz-Cazares, Bayona-Saez, and Garcia-Marco 2013; Hashimoto and Haneda 2008). The innovation outputs of the commercialization stage are measured as the transaction volume of the technology market and the sales revenue derived from new products within high-tech industries. The transaction value, in this context, serves as the level of marketization. We suppose that it takes approximately 1 year to transform R&D inputs into concrete innovation output. There can be variable returns to scale.

3.2.2. Independent variable

International R&D capital stock(S^f).We follow Lichtenberg and van Pottelsberghe (1998) in applying the weighting scheme to the spillover variables. Foreign R&D capital stock is defined as:

$$S_{it}^f = \sum_{j \neq i} \left[\frac{M_{ijt}}{Y_{jt}} \right] S_{jt}^d \tag{8}$$

where S_{it}^f denotes the annual stock of foreign R&D knowledge that is transmitted by import from country j to country i at period t.M_{ijt} denotes the imports from country j to country i at time t.Y_{jt} refers to the GDP of country j.S_{jt}^d represents the domestic knowledge stocks of country j.

We employed the perpetual inventory method (PIM) to calculate R&D stocks of different regions in our model. In the PIM, the equation for calculating R&D stock is as follows:

$$S_{it}^d = (1 - \delta) S_{it-1}^d + R_{it} \tag{9}$$

Where S_{it}^d and R_{it} represent domestic R&D stock and R&D expenditure at year t in country i respectively, and δ is the depreciation rate which is assumed to be 15%. R&D expenditures are converted to their 2000 constant values by GDP deflators.

The starting value for stock S_0 is calculated as:

$$S_0^d = {}^{R_0}/_{(\delta + g)} \tag{10}$$

where g is the annual average growth of R&D expenditure over the period. R_0^d is the R&D expenditures during the base period.

4. Moderating variable

Strength of IPR protection (IPR). Effective IPR protection should account for both the level of intellectual property (IP) book-law protection and the actual enforcement levels. To measure the strength of IPR protection accurately, we propose the following specification:

$$IPR_{it} = GP \times F_{it} \tag{11}$$

where Ginarte and Park (1997) index, commonly denoted as GP, is widely employed as a standard measure for assessing the strength of national IPR protection. This index was later extended by Park (2008). It encompasses five core dimensions: patent coverage, membership of countries in international agreements, duration of patent, enforcement mechanisms available and provisions against losses of protection (Papageorgiadis and Sharma 2016). The GP index is commonly used as a proxy for patent protection in term of statutory provisions.

Given the uniformity of intellectual property legislation across China, the *GP* index is the same in all regions. Thus, the enforcement of IPR laws is a critical issue. However, substantial cross-regional disparities in the enforcement of intellectual property laws persist (Kafouros et al. 2015), attributable to the unbalanced socio-economic development across regions. Indicator F_{it} denotes the level of enforcement-related aspects in year t at region i. Following Ostergard (2000) and Xu and Guang Shan (2008), the enforcement of IPR comprises two dimensions that involve their capacity, together with the general willingness to enforce the laws. The first dimension includes the level of judicial protection and the adequacy of legal system. We use the ratio of lawyers to the population in a specific region to measure the level of judicial protection. It is worth noting that litigation volumes in China are generally small and the spatial distribution of cases is highly uneven. According to a report from Beijing evening news, Beijing showed the highest lawyer-to-population ratio in 2012, with 11 lawyers per 10,000 individuals. Conversely, five provinces had fewer than one lawyer per 10,000 people. Therefore, we posit that when the regional layer-to-population ratio reaches five per 10,000, the level of judicial protection reaches a relatively high level. When the ratio is up to 5 out of 10000 in a region, the score is 1. Otherwise, the score is calculated as the actual ratio divided by five ten-thousandths. As for the adequacy of legal system, we contend that the longer the legislative history, the more perfect the legal framework in China. Thus, legislative time is used as a proxy for this dimension. The second element includes the level of regional economic development and the social awareness towards infringing goods. Prior research (Ginarte and Park 1997; Papageorgiadis, Cross, and Alexiou 2014; Pryor 2006; Thompson and Rushing 1999) indicates a positive correlation between GDP per capita and the strength of patent protection. According to the World Bank's Classification, the average GDP per capita of lower middle-income countries was about $2250 for the period 2001–2009. When the GDP per capita of a region is beyond the average GDP per capita of lower middle-income countries, the region receives a value of 1. Otherwise, we assigned a value by using the GDP per capita of the region to divide the average GDP per capita. According to statistic from the World Bank, China has reached the level of upper-middle income country. For the years 2010–2020, the average GDP per capita of upper-middle income countries was about $8100. We use a similar method to calculate the scores. Social awareness is measured by the number of patents per 10,000 people. The score of every factor is between 0 and 1. Where 0 represents the absence of IPR enforcement and 1 denotes the highest level of enforcement. These two components are complementary and we have taken a simple average for the four terms.

5. Control variables

To mitigate the endogeneity caused by omitted variables, some control variables are added which may affect regional innovation activities. (1) Regional GDP (GDP). A higher GDP level can provide more market opportunities for innovation. (2) Human capital Level(HR). Technological innovation is intrinsically linked to educational attainment. We adopt the adult literacy rate as a proxy indicator for this variable. (3) Openness (OPEN). We use the ratio of foreign direct investment (FDI) inflows to the regional GDP to measure it. (4) Information Infrastructure Level (INF). Considering data availability, we employ the ratio of the total business volume of postal and telecommunications services to the regional GDP to measure it.

5.1. Data

Our empirical estimation involves 30 provinces of China. In the analysis of innovation efficiency dynamic, the Malmquist index for a year is usually compared to the preceding year. Accordingly, the sample period is from 2000 to 2020. For other panel data, including the comprehensive regional level dataset in China is from the years 2001 to 2020. The data on regional GDP, import volume, and FDI inflows were collected from the National Bureau of Statistics of China. The information on intramural R&D expenditures, invention patent application numbers, and full-time equivalent of R&D personnel across the 30 provinces was extracted from the China Statistical Yearbook on Science and Technology. Data regarding the population for the 30 provinces were obtained from China Statistical Yearbook. The share of R&D expenditure in GDP (GERD) of the G7,[1] alongside the nominal GDP of the G7 were derived from the OECD's Main Science and Technology Indicators. The GDP deflators for the G7 were calculated according to the World Bank database. The population of lawyers is from the Chinese Yearbook of lawyers. Table 3 provides descriptions of the variables used for Malmquist DEA analysis. Table 4 presents the basic statistics of the variables in empirical model.

Table 3. Variables description of Malmquist index analysis.

Variables	Definition	Mean	Std.Dev
Invention patent application (outputs at stage 1)	The total number of invention patent applications at the regional level per year	11314.41	133.64
Transaction volume (outputs at stage 2)	The value of technology market transaction per year	5000	10000
Sales revenue of new products (outputs at stage 2)	The revenue from new products in high-tech sectors	50000	50000
Intramural expenditure on R&D (inputs)	Region's annual internal R&D expenditure	1664967	561919.1
Full-time equivalent of R&D personnel (inputs)	The total number of full-time R&D employees and the converted full-time equivalent of other part-time R&D personnel annually	67792.38	47929.11

Table 4. Descriptive statistics of the variables.

Variables	Definition	Mean	Std. Dev	Min	Max
RE	Log of R&D efficiency	0.056	0.241	−0.685	0.67
CE	Log of commercialization efficiency	−0.0119	0.414	−1.11	1.09
S^f	Log of International R&D capital stocks	6.66	3.01	0.95	20.38
IPR	Log of the strength of IPR protection	0.839	0.413	−0.316	1.419
OPEN	Log of the proportion of FDI inflows to GDP	−1.203	0.89	−3.05	3.53
GDP	Log of the regional GDP	9.184	1.135	5.698	11.615
HR	Log of adult literacy rate	4.529	0.534	4.254	4.593
INF	Log of the ratio of total business volume of postal and telecommunications services to regional GDP	−2.909	0.5726	−4.244	−1.239

6. Results

6.1. R&D efficiency and commercialization efficiency

The R&D efficiency and commercialization efficiency were estimated by using the DEAP 2.1 software. Table 5 reports the mean of R&D efficiency and commercialization efficiency across all regions in China. Notably, the eastern region has the highest R&D efficiency, especially in Beijing, Shanghai, and Shandong provinces. While that of the western region is the lowest, with Ningxia provinces recording the lowest scores. Across all regions, commercialization efficiency is lower than R&D efficiency, indicating a relatively low commercialization rate in China. Among all regions, Xinjiang province attains the lowest scores in commercialization efficiency.

6.2. Main results

At the beginning of the analysis, we performed a variance inflation factor (VIF) test and found no serious multicollinearity. We mean-centred all variables in the interaction terms to avoid multicollinearity issues (Xiao and Il Park 2018). The Hausman test is conducted to choose the appropriate method. The results show that fixed-effects models are suitable for our analyses. To address the problem of unobserved heterogeneity, we use clustered robust standard errors to correct for heteroskedasticity. The main results are reported in Table 6.

Import spillovers have exerted differentiated effects on R&D efficiency and commercialization efficiency. Model (1) in Table 6 examines the impact of import spillovers on regional R&D efficiency. The findings indicate that the import spillovers exert a significantly positive impact on R&D efficiency. This phenomenon can be attributed to the following factors. First, reduced input tariffs facilitate the availability of a large quantity of input with more varieties and a higher quality. More advanced intermediate inputs and equipment can be acquired through imports (W. Chen 2017). Furthermore, diversified knowledge embedded within imported inputs and equipment serves to enhance the knowledge creation (X. Liu, Ji, and Ge 2024). Model (3) in Table 6 examines the impact of import spillovers on commercialization efficiency. The results are negative

Table 5. The mean of R&D efficiency and commercialization efficiency.

Region	R&D Efficiency	Commercialization efficiency	Region	R&D Efficiency	Commercialization efficiency
Beijing	1.128	1.07	Heilongjiang	1.040	1.012
Tianjin	1.098	0.969	Anhui	1.123	1.039
Hebei	1.052	1.005	Jiangxi	1.042	0.989
Liaoning	1.081	1.017	Henan	1.007	0.957
Shanghai	1.062	1.009	Hunan	1.042	0.99
Jiangsu	1.119	0.969	Hubei	1.074	1.014
Zhejiang	1.051	0.936	Chongqing	1.054	0.914
Fujian	1.052	0.898	Sichuan	1.111	0.993
Shandong	1.102	0.966	Guizhou	1.024	1.032
Guangdong	1.095	0.978	Yunnan	1.001	0.935
Guangxi	1.000	0.94	Shanaxi	1.054	1.144
Hainan	1.007	0.906	Gansu	1.054	1.074
Shanxi	1.024	1.102	Qinghai	1.043	1.054
Neimenggu	0.977	0.908	Ningxia	0.970	0.939
Jilin	1.029	1.065	Xinjiang	1.017	0.881

Table 6. Estimates of regional innovation efficiency.

Variables	(1) RE	(2) RE	(3) CE	(4) CE
log S^f	0.005*	−0.0099*	−0.0003	0.0182**
	(0.0032)	(0.052)	(0.0029)	(0.0079)
log *IPR*	0.13***	0.412***	−0.0266	0.0317
	(0.264)	(0.0512)	(0.432)	(0.07)
ln $S^f * \ln IPR$		0.0097**		−0.0167**
		(0.0046)		(0.008)
log *GDP*	0.00186	0.0053	0.019**	−0.0035
	(0.008)	(0.008)	(0.010)	(0.0136)
log *HR*	−0.277***	−0.286*	−0.228*	−0.303*
	(0.109)	(0.152)	(0.137)	(0.155)
log *INF*	−0.0929***	−0.0976***	0.011	−0.0062
	(0.0134)	(0.0148)	(0.014)	(0.014)
log *OPEN*	−0.0041	0.0152*	0.002	−0.0147
	(0.008)	(0.0081)	(0.01)	(0.012)
$(\log IPR)^2$		−0.244***		0.0903
		(0.0351)		(0.055)
Constant	0.974***	0.95	0.786	1.126*
	(0.49)	(0.69)	(0.587)	(0.649)
Year dummy	yes	yes	yes	yes
Observations	600	600	600	600

Note: ***significant at 0.01 **significant at 0.05 * significant at 0.1.

and insignificant. The intensified competition engendered by imports diminishes the profitability of indigenous firms, leading to a crowding-out effect whereby imported products displace new products form domestic enterprises.

Regarding IPR protection, Model (1) and (2) in Table 6 show that IPR protection is significantly and positively related to R&D efficiency. This finding implies that strong IPR protection can enhance R&D efficiency. A stringent IPR regime empowers innovators to secure monopoly profits, thereby incentivizing knowledge creators to allocate greater resources to R&D endeavors. To fully understand the curvilinear relationship, we incorporated both the linear and quadratic effects of IPR protection. Model (2) in Table 6 demonstrates an inverted-U curve between the strength of IPR protection and R&D efficiency, suggesting that IPR protection reaches a certain point, the monopolistic impact of IPR strength tends to dominate the market expansion effect. Our results are generally consistent with the findings of Hudson and Minea (2013). While the IPR protection has an insignificantly negative impact on commercialization efficiency as shown in Model (3) in Table 6. The results from Model (4) in Table 6 show that the IPR protection and its squared term have an insignificantly positive effect on commercialization efficiency. It means that strict IPR is advantageous for the commercialization-oriented innovation pursued by entrepreneurial firms. It ensures that start-ups can earn more innovative rents stemming from commercialization efforts (Hou et al. 2023).

In Model (2) and (4) presented in Table 6, the interaction term between the strength of IPR protection and import spillovers is added. In Model (2), the interaction term between IPR protection and import spillovers demonstrates a significant and positive (model2:b = 0.0097,$p < 0.05$), implying that IPR protection positively moderates the relationship between import spillovers and R&D efficiency. The absorptive capacity plays a critical role in the assimilation of new knowledge. Rigorous IPR protection forces domestic firms to increase in-house R&D, thereby enhancing their absorptive capacity (X. Li 2011).

Furthermore, indigenous firms realize that independent innovation is essentially driven by fierce competition (Huang, Geng, and Wang 2017). However, Model (4) in Table 6 shows that the coefficients of the interaction between the strength of IPR protection and import spillovers are significant yet negative ($b = -0.015$, $p < 0.05$). Strict IPR protection creates monopoly power. Reduced competition, in turn diminishes profits and also hampers R&D investment among indigenous firms. There is a crowding-out effect of import products to domestic enterprises. On the other hand, the increased IPR protection raises the costs of imitation and infringement for local companies. Second, strong IPR protection may hinder sequential innovations in complex industries (Woo, Jang, and Kim 2015).

Turning to the control variables, we observe that the openness has an insignificantly negative impact on R&D efficiency as shown in Model (1) of Table 6, which is consistent with the findings of Fu and Gong (2011). Domestic firms prefer direct adoption of existing technologies to the investment in in-house R&D, resulting in a lack of core technologies. The human resource level negatively influences R&D efficiency, suggesting that a scarcity of high-skilled talent may hinder technical upgrading in China. Alternatively, there may be an inefficient allocation of human resources. GDP has exerted a positive effect on R&D efficiency in Model (2) of Table 6 ($b = 0.026$, $p < 0.05$), reflecting that domestic demand can effectively stimulate technological progress to a certain extent. The level of information has a negative and significant impact on R&D efficiency. However, it has an insignificantly positive impact on commercialization efficiency. The advancement of e-commerce has, to some degree, promoted commercial innovation.

6.3. Robustness checks

Additional analyses were performed to test the robustness of the results. We analyzed the model by changing the measurement of innovation efficiency. We used the innovation inputs, measured as R&D investment, and the innovation outputs, measured as the number of invention patent applications at the provincial level to examine the impact of import spillovers. The result shows that import spillovers are positively and significantly related to innovation outputs in Model (3) of Table 7, whereas the relationship with investment is insignificant. This suggests that import spillovers may stimulate the patent application. In Model (4) of Table 7, the finding shows that the moderating effect of IPR enforcement is positive and significant for innovation outputs. However, for innovation inputs, the effect is not significant in Model (2). The direction of the coefficient is consistent with the results of Model (2) of Table 6 overall. It implies that diversification of imported inputs incentives domestic firms to invest in new knowledge generation.

6.4. Further analysis

China's economy differs in terms of its development.[2] Since the initiation of China's opening-up policy, local governments have enjoyed greater autonomy in policy formulation and IPR enforcement (Hou et al. 2023). Consequently, significant institutional heterogeneity exists across regions (Sun et al. 2017). To analyze this heterogeneity between provinces, we categorized the sample into three clusters based on China's regional development geography (X. Liu, Ji, and Ge 2024). Taking China as a case study allows us

Table 7. Robustness check by using two methods.

	(1) Alternative measure of R&D investment		(2) Alternative measure of patent application	
Variables	Model (1)	Model (2)	Model (3)	Model (4)
log S^f	0.0042	0.0038	0.0076***	−0.0198***
	(0.005)	(0.0058)	(0.0024)	(0.0065)
log *IPR*	0.303	−0.079	0.759***	−0.554***
	(0.2)	(0.104)	(0.0402)	(0.132)
ln S^f ∗ ln *IPR*		0.0045		0.0993***
		(0.0118)		(0.0188)
log *GDP*	1.192***	1.212***	1.008***	1.018***
	(0.0152)	(0.014)	(0.0264)	(0.0315)
log *HR*	0.656***	0.388**	0.0521	0.0911
	(0.117)	(0.154)	(0.238)	(0.277)
log *INF*	0.0111	0.0159	−0.211***	−0.199***
	(0.0266)	(0.0204)	(0.0478)	(0.0455)
log *OPEN*	0.0637***	−0.0587***	0.125***	0.0992***
	(0.0067)	(0.0055)	(0.0083)	(0.0057)
$(\log IPR)^2$		0.418***		1.045***
		(0.068)		(0.0807)
Constant	−0.167	0.853	−0.684	−0.769
	(0.513)	(0.648)	(1.085)	(0.99)
Year dummy	yes	yes	yes	yes
Observations	600	600	600	600

***significant at 0.01 **significant at 0.05 * significant at 0.1.

to better analyze the effects of import spillovers on innovation under varying levels of IPR protection nationwide.

To further investigate the heterogeneous effects of import spillovers on innovation efficiency across regions, we divide our sample into three sub-samples according to China's regional development geography. The regions in eastern China are more developed. Regions in central and western China are relatively backward in term of economic development. The empirical results are presented in Tables 8 and 9, respectively.

Table 8. Empirical estimates of R&D efficiency.

	Eastern region		Central region		Western region	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−1.583	−1.414	8.956**	7.781*	1.769	2.091
	(1.300)	(1.332)	(3.316)	(4.706)	(2.172)	(2.188)
ln S^f	−0.0039*	−0.0033	0.00864	0.0432	−0.00194	0.0093
	(0.005)	(0.0108)	(0.0084)	(0.0271)	(0.0115)	(0.0185)
lnIPR	0.798***	0.785***	0.751**	0.914***	0.331	0.405*
	(0.11)	(0.128)	(0.271)	(0.278)	(0.209)	(0.234)
ln S^f ∗ ln *IPR*		0.108*		−0.0423		−0.0202
		(0.0632)		(0.0442)		(0.023)
LnGDP	0.0128	0.0121	−0.284*	−0.316**	0.0389	0.0473
	(0.015)	(0.0153)	(0.137)	(0.151)	(0.0304)	(0.03)
LnOPEN	0.0275*	0.0261*	0.0672	0.0587	−0.0322	−0.0299
	(0.0141)	(0.0151)	(0.0411)	(0.0667)	(0.0376)	(0.037)
LnINF	−0.0526**	−0.049**	−0.230***	−0.234***	−0.125***	−0.13***
	(0.023)	(0.0231)	(0.0367)	(0.0463)	(0.045)	(0.2263)
LnHR	0.265	0.23	−1.563**	−1.39	−0.568	−0.666
	(0.282)	(0.291)	(0.667)	(1.101)	(0.52)	(0.528)
$(\mathrm{lnIPR})^2$		−0.398***	−0.216	−0.127	−0.23*	−0.191
		(0.0819)	(0.183)	(0.18)	(0.133)	(0.14)
Year dummy	yes	yes	yes	yes	yes	yes
Observations	220	220	160	160	220	220

***significant at 0.01 **significant at 0.05 * significant at 0.1.

Table 9. Empirical estimates of commercialization efficiency.

	Eastern region		Central region		Western region	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−1.298	−0.854	1.983	1.765	3.267	3.781
	(2.116)	(2.144)	(6.336)	(5.75)	(2.905)	(2.988)
log S^f	0.0045	0.0523**	−0.00695*	−0.0205	0.0215	0.0065
	(0.0057)	(0.0222)	(0.00306)	(0.0369)	(0.0158)	(0.026)
IPR	1.039***	1.019***	−0.559	0.106	−0.214	−0.31
	(0.277)	(0.265)	(0.206)	(0.39)	(0.255)	(0.285)
LnGDP	−0.0246	−0.0293*	−0.147	−0.178	−0.0066	−0.0176
	(0.016)	(0.0198)	(0.172)	(0.149)	(0.049)	(0.054)
LnOPEN	−0.011	−0.0104	−0.0253	−0.024	−0.0321	−0.0295
	(0.0198)	(0.019)	(0.097)	(0.101)	(0.0614)	(0.0619)
LnINF	0.0496*	0.0584**	−0.0837	0.0971	−0.0718	−0.0647
	(0.028)	(0.0295)	(0.091)	(0.0916)	(0.0579)	(0.059)
LnHR	0.235	0.105	0.0231	0.0172	−1.523*	−1.394*
	(0.453)	(0.455)	(0.0334)	(0.0338)	(0.814)	(0.843)
$(\text{LnIPR})^2$	−0.511***	−0.334**	0.4173	0.4739	0.198	0.145
	(0.138)	(0.149)	(0.176)	(0.181)	(0.177)	(0.193)
$\ln S^f * \ln IPR$		−0.0406***		−0.0328		0.0267
		(0.0155)		(0.0328)		(0.038)
Year dummy	yes	yes	yes	yes	yes	yes
Observations	220	220	160	160	220	220

***significant at 0.01 **significant at 0.05 * significant at 0.1.

Model (1) in Table 8 indicates that the impact of import spillovers on R&D efficiency in eastern region is negative and significant. However, the interaction term exhibits a significant and positive coefficient for eastern China ($b = 0.108, p < 10\%$). For firms possessing a certain level of technological level, in-house R&D facilitates the assimilation and utilization of complex knowledge, thereby building up innovation capability (X. Liu, Ji, and Ge 2024). The central region has similar results (as shown in Model (4)), as dose the western region (Model(6)). The interaction coefficients are insignificantly negative. Import competition stimulates the domestic firms' innovation when firms are close to the world frontier (Sai, Puyang, and Wei 2015). The central and western regions are less developed, and firms in these regions lag behind the frontier technology. The increased import competition dampens the innovation. These regions, constrained by a lack of scientific knowledge and the talents, rely more on cost-oriented innovation strategies, such as the acquisition and adoption of imported machinery and equipment (Vujanović et al. 2022).

Strict IPR protection increases the cost of knowledge acquisition and recombination. As shown in Model (1), (3) and (5) of Table 8, the IPR protection and R&D efficiency present an inverted U-shaped relationship. Excessive IPR protection may inhibit R&D efficiency.

Table 9 reports the regression results regarding import spillovers on commercialization efficiency. The results from Model (1) and (5) in Table 9 show that import spillovers have an insignificantly positive impact on commercialization efficiency in the eastern and western regions, implying a weak and positive technology spillovers effect on commercialization in these areas. By contrast, the coefficient in Model (3) shows that import spillovers are significantly and negatively related to commercialization efficiency ($b = -0.00695, p < 0.1$). It means that import spillovers inhibit the commercialization efficiency in central China. Regarding the moderating effect of IPR protection, Models (2), (4), and (6) in Table 9 present the regression results. In the eastern region, the coefficient of the interaction term between IPR protection and import spillovers is negative and significant

(Model (2)). In contrast, the regression coefficient of interaction term is positive but not statistically significant in the western region (Model (6)).

Regarding the control variables, FDI has a significant and positive impact on the R&D efficiency in eastern China. The level of information infrastructure has a negative and significant impact across all regions, suggesting that enterprises, universities, and other institutions have failed to establish effective digital platforms to enable information sharing and enhance R&D efficiency.

7. Discussions and conclusions

7.1. Conclusion

In the study, we propose a novel framework for analyzing regional innovation efficiency, by using panel dataset covering 30 provinces from 2001 to 2020. The results indicate the coexistent of two opposing mechanisms of import spillovers: learning effects and adverse crowd-out effects. We found that import spillovers have a positive influence on R&D efficiency. Increased import diversity is found to foster new knowledge creation. In-house R&D serves to strengthen firms' absorptive capacity (Cohen and Levinthal 1989). The study identifies that the strength of IPR protection has significant explanatory power with regard to the effect of import spillovers on R&D efficiency across different regions in China. The interaction between import spillovers and IPR protection effectively triggers improvements in R&D efficiency. The effect is significant in the eastern regions, whereas it has the opposite and insignificant effect in central and western regions.

Regarding commercialization efficiency, the findings indicate that IPR protection negatively moderates the relationship between import spillovers and commercialization. The results conform to the findings of Q. Liu and Qiu (2016a). It is worth noting that the level of information development has a negative and significant impact on R&D efficiency. This implies that current digital development has failed to enhance R&D efficiency, though it shows an insignificantly positive effect on commercialization efficiency.

7.2. Managerial implications

There are several implications for stakeholders. First, policies should stimulate diversified imports, particularly of key equipment. However, the potential substitution effect should be recognized. Local governments in eastern China should design and update the innovation systems, including establishing cooperative networks and facilitating the flow of innovation elements. Governments in central and western China should encourage firms to leverage external knowledge while simultaneously investing in internal R&D to improve both R&D and commercialization efficiency. Second, the enforcement of IPR protection must be tailored to level of local economic development. Specially, IPR protection should be strengthened in the eastern regions to stimulate independent innovation capabilities. In contrast, a relatively loose IPR protection is necessary in less developed regions to facilitate knowledge diffusion. Third, the government should establish R&D platforms that bridge the gap between basic research and market demand, thereby accelerating the commercialization of new knowledge.

Although the study focuses on the Chinese situation, most of our findings in the analysis can also offer guidelines on innovation and catch-up strategies for other developing economies. First, the acquisition of international R&D knowledge, and thereby of building technological capacities, is dependent on the local absorptive capacity. Second, the design of IPR protection regimes must adapt to the technological capacities of local firms.

7.3. Limitation

This study has several limitations. First, the analysis is based on provincial-level data from China. Future studies could extend this study in firm level or other economies. Second, this study primarily examines how the import spillovers influence innovation efficiency across different regional IPR protection strength in China. It would be valuable for future to test if and how other institutional differences influence the effect of import spillovers on innovation process.

Notes

1. The G7 is group of seven countries which include Canada, U.S.A., U.K., Japan, Italy, Germany, and France.
2. We divided China into eastern, central, and western regions according to the economic development. The eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the central region includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hunan, and Hube; and the Western region includes Neimenggu, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shananxi, Gansu, Qinghai, Ningxia, and Xinjiang.

Author contributions

CRediT: **Juan Tu:** Conceptualization, Formal analysis, Writing – original draft; **Zhiying Liu:** Methodology, Supervision, Funding acquisition; **Kaicheng Zhao:** Investigation, Writing – review & editing; **Gaojiong Wu:** Software, Data curation, Visualization; **Zhiyong Li:** Project administration, Resources, Validation.

Disclosure statement

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