Xie et al. Frontiers of Business Research in China (2017) 11:14
DOI 10.1186/s11782-017-0014-6

Frontiers of Business Research in China

RESEARCH Open Access

The effect of domestic and foreign trade coordination on technological innovation: complements or substitutes?

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Abstract

Based on the theory of technology spillover in international trade, this paper discusses the technological innovation effect of trade by taking the influence of domestic trade into account. Under the constraint of the production possibility frontier, there is either complementarity or substitutability between domestic and foreign trade. It must be decided whether resources should be concentrated in one of the sectors (*trade specialization*) or instead allocated equally (*trade equalization*) between the two sectors. This paper firstly discusses how domestic trade and foreign trade work together to influence technological innovation, and how trade equalization and specialization affect different types of innovation. Using a provincial-level panel dataset from 2007 to 2015 in China, this paper constructs the indicators of domestic and foreign trade linkage and examines the impact of trade on innovation. The findings show that trade equalization mainly promotes incremental innovation, while trade specialization improves radical innovation. Thus, in the area of incremental innovation, attention should be paid to the equalized development of domestic and foreign trade, while in areas pursuing radical innovation, emphasis should be put on the specialization of the trade sector, avoiding equal allocation of resources to the two sectors.

Keywords: Domestic and foreign trade coordination, Technological innovation effect, Radical innovation, Incremental innovation

Introduction

In Solow's economic growth model, when a country's capital-labor input reaches a stable state, the technical level is the driving force leading to further economic growth, and technological innovation is an important source of technological progress. Great emphasis has always been placed on trade among the numerous and complicated factors affecting technological innovation. The relevant studies mainly focus on the technological innovation effect from the perspective of international trade, however, and rarely consider the linkage effect of domestic trade.

The main conclusions of the existing literature focusing on international trade note that the technological innovation effect of trade can simultaneously influence both importers and exporters. International trade can either improve the technological level of the production activities in the importing country through high-quality intermediate products (Tradee and Helpman, 1993; Grossman and Helpman, 1991), or improve the technological level of the exporting country by means of Original Equipment Manufacturer as well as processing trade. Some studies argue that the positive impact of foreign trade on technological innovation is confined to developed countries (Coe and Helpman, 1995). They propose that developing countries likely lose the technological innovation capacity of their local firms in foreign trade due to low-end lock in the value chain and excessive reliance on international markets (Stokey, 1991; Young, 1991). Due to differences related to economic development and industrial competition, the actual effect of trade on technology innovation is changing. This paper argues that the coordination between domestic and foreign trade reflects the complexity of trade in a country's market (especially in large markets). Recent empirical literature also points to the close relationship between domestic and foreign trade. Domestic trade can promote adjustments to the export propensity by strengthening supply-demand matching and reducing market fragmentation and transaction costs (Zhang, 2014). In addition, domestic trade may also enhance the technical spillover effect of foreign trade and may lead to additional technology spillover effects via the tight connections between the two trading sectors.

In addition to the refinement of trade indicators, the core issue is to further identify how to make trade arrangements so that they have a positive impact, while avoiding the negative effects of trade on technological innovation. It is important to consider *equalization* and *specialization* between domestic and foreign trade when the coordination of these factors is included in research on the technological spillover effect. Regardless of the economic integration among different countries, there have always been professional activities in domestic and foreign trade sectors since they follow different paradigms and are subject to different trading rules. Under the constraint of the production possibility frontier, it must be decided how the resources are allocated between the two major trade sectors. The resources can be concentrated in one of the sectors, referred to as *specialization* (or *trade specialization*) in this paper. The resources can instead be allocated equally between the two sectors, referred to as *equalization* (or *trade equalization*). Therefore, the two major trade sectors (domestic and foreign) should coordinate and interconnect. The various effects of equalization and specialization of the two sectors also need to be considered. Based on the theory of technology spillover in international trade, this paper discusses the technological innovation effect of trade by taking the influence of domestic trade into account and constructing the indicators of domestic and foreign trade linkage.

The contribution of the paper lies in the following aspects: First, previous research has primarily focused on the relationship between international trade and technological innovation, while ignoring the impact of domestic trade. This paper, by measuring the level of coordinated development between domestic and foreign trade, more comprehensively examines the impact of trade on technological innovation. Second, under the condition of resource constraint, there is either complementarity (*trade equalization*) or substitutability *(trade specialization*) between domestic and foreign trade in the development of the two sectors. Having considered theories of technology spillover as well as equalization and specialization of the two trading sectors, this paper analyzes the mechanism of how coordinated development of trade affects technological innovation. Thirdly, some studies classify innovation into radical innovation and incremental innovation (March, 1991). This paper analyzes the impact of trade equalization and specialization on different types of innovation.

The article is structured as follows: Section 2, focusing on the perspective of technology spillover, discusses how the coordinated development of domestic trade and international trade work together to influence technological innovation, and how trade equalization and specialization affect different types of innovation. Section 3 constructs the index of trade coordination and describes empirical tests using the fixed-effect model, the panel quantile model and so on. Section 4 discusses the conclusions and implications for future research.

Mechanism analysis and literature review

Domestic and foreign trade coordination: Enhancement of technology spillover

The existing literature discusses the impact of international trade on innovation from the perspective of technology spillover, which mainly includes competition, imitation as well as upstream and downstream contact (Alyson, 2006; Grog and Greenaway, 2002). In Krugman's model (Krugman, 1979), export growth provides technological innovation benefits. As monopolies end and the technology gap narrows, trade competition further promotes technological innovation. In addition, the non-trade sector may benefit from technology spillover by imitating and learning the technology from the trading sector (Fosfuri, 2001; Feder, 2006). An industry's technological innovation will, based on this, also lead to technological progress of related industries due to the technical and economic links between them. For example, multinational companies have put forward higher technical requirements for manufacturers in the processing trade, while manufacturers also require a higher level of technology for suppliers of raw materials and components (Kneller and Pisu, 2007).

There is, however, an underlying problem in that technology spillover of foreign trade does not affect countries at different stages of development in the same manner. Hence, trade does not always have a positive effect on technological innovation. In some developing countries, especially where the industries are controlled by transnational corporations, trade will continue to be locked at the low end of the value chain (Schmitz and Knorringa, 2000). At the same time, the comparative advantages of developing countries are concentrated in traditional industries because of their dependence on labor endowments. Therefore, the technology spillover is weak in these countries, making it difficult to promote technological innovation. In essence, whether the technical spillover of foreign trade can play a positive role depends largely on whether there are tight technical and economic connections among domestic industrial sectors. How the industrial sectors conduct international trade drives the technological development of the rest of the industries through the diffusion effect, including the forward effect, the bystander effect and the retrospective effect (Rowstow, 1990).

In view of possible adjustments and coping strategies, one feasible way for developing countries to improve technological spillover is to choose industrial sectors with large diffusion effects for international trade activities. Developing countries, however, are often forced to be low-locked in the global value chain due to their own resource endowments, division of global value chains and various other reasons (Gereffi, 1999; Cramer, 1999). Another feasible idea is to promote technological spillover by strengthening the diffusion effect of the industrial sectors, in which processes of domestic trade can play a role by adjusting the matching of production and demand, and also by reducing inter-regional market fragmentation (Zhang Hao, 2014). So far, few studies have analyzed the impact of domestic trade.

This paper argues that the interaction between domestic and foreign trade (trade coordination) can affect the technological spillover effect by improving competition, imitation and upstream and downstream contact, etc., which will then affect technological innovation. The ways are referred to as the competitive driving effect, the information diffusion effect and the value chain optimization effect in this paper.

The competitive driving effect

If FDI is dominated by foreign enterprises, these absorb local resources and have a significant impact on the competitive landscape (Konings, 2001). Similarly, if foreign trade is overly developed in a region, competition between foreign goods and domestic goods will intensify. The results are that the local market may show excessive dependence on overseas products, making it difficult for local enterprises to obtain innovative resources. The fierce competitive environment may, however, also stimulate local enterprises to make more efforts to improve technological innovation. The local enterprises can obtain the competitive advantage through innovation of products, crafts, markets, etc. Meanwhile, such developed domestic trade also reduces the transaction cost and enhances the competence of local enterprises. The enterprises can realize innovation revenues through the sale of innovative products. At the same time, the motivation to innovate and the continuous investments in R&D of the companies may be weakened if they are in a relatively relaxed competitive environment.

The information diffusion effect

Market information is an important factor influencing the imitation and innovation activities of enterprises. Enterprises can imitate and improve mature products in the market and thereby realize an imitation innovation effect with the help of market information. In areas where domestic trade is more active, market information and market demand can spread to businesses easier and quicker due to faster economic cycles, and thus act on imitation innovation (Sjöholm, 1996). In addition, innovative products can be tested by the market in a timely manner, which is conducive to making adjustments or carrying out secondary innovation according to market feedback. In this process, foreign trade plays the role of information sources. Contrastingly, in areas where foreign trade is developed, the overseas qualified product information, as well as technical information, can flow in a timely manner to the local enterprises. Thus, local enterprises can learn from foreign technology or products and implement a reverse crack on them, through which innovation costs can be reduced and innovation efficiency can be improved.

The value chain optimization effect

Foreign trade provides a broader market of raw materials and commodities for local enterprises. This makes it possible for them to allocate resources on a global scale, purchase overseas production factors with higher quality and gain markets with more extensive commodities. Generally speaking, foreign trade not only provides more convenient conditions for enterprises to carry out innovative activities, but also stimulates enterprises to obtain higher profit through continuous technological innovation. Limited by capital, talent and other factors, however, some domestic enterprises fail to enter international markets independently. In addition, the search and transaction costs to gain access to overseas resources are higher. Under this circumstance, domestic trade can act as a business synthesizer to connect domestic and foreign markets by virtue of advantages in information, services, logistics, etc. Compared to overseas markets, dominating enterprises in the field of domestic trade have a better knowledge of the demand and products in the domestic market. On the basis of this, enterprises can further access international markets and resources through other major international trade enterprises and build the bridge of "re-intermediary" between domestic and foreign markets. These enterprises can also directly engage in international trade activities and provide service support for domestic enterprises to get involved in international trade. In other words, developed domestic trade will enable international markets and resources to better integrate into the value chain of local enterprises.

Coordinative development and types of innovation

Domestic and foreign trade, which complement each other and form a complete category of trade, have relatively independent specialized activities. The coordinated development of the two sectors reflects the integration of internal and external markets as well as the interwork of resources and factors from the perspective of globalization. This does not mean, however, that the professional boundaries of the two are disappearing. Under the constraints of the production possibility frontier, there are two different development paths when it comes to the coordination between domestic and foreign trade. One is to invest in relatively less developed sectors in order to achieve a balanced development of domestic and foreign trade. The other is to focus on the higher developed trade sector, in which enterprises can avoid weaknesses and maximize the specialized superiority of domestic or foreign trade. The former is in this paper referred to as *equalization* (or *trade equalization*), and the latter is called *specialization* (or *trade specialization*).

How will these two different pathways affect technological innovation?

One possible answer is that the different development paths will have different effects depending on the type of innovation. As noted, innovation can be classified into radical innovation and incremental innovation (March, 1991). Radical innovation refers to breaking the existing technological path and reforming products or services (Chandy and Tellis, 2013; Subramaniam and Youndt, 2005), while incremental innovation improves and develops the existing technical pathways by refining and enhancing existing technology or ability (Ettlie, 1983; Gatignon and Tushman, 2002). In regard to the coordination of domestic and foreign trade, equalized development will make a stronger contribution to incremental innovation, while specialized development will be more conducive to radical innovation.[1]

In regard to the competitive driving effect, an improvement of a specialized level of the domestic or foreign trade sector means that the degree of competition increases, bringing about a stronger driving force for the enterprises to carry out radical innovation. The rules of competition will then be directly changed by new products or new services that result from the kind of innovation which substitutes for existing products or services (Rao et al, 2013). If the two trade sectors develop simultaneously, however, the competitive pressure on the enterprises will decrease, which is more in line with the characteristics of low risk, low exploration and low creativity of incremental technological innovation (Olson, 1995).

In terms of the information diffusion effect, the specialization of certain trade sectors leads to faster information diffusion and higher quality information sources. This is conducive to the formation of knowledge transfer capacity required by radical innovation, leading enterprises to have a non-linear access to other types of knowledge. The equal development of the trade sectors will, however, help enterprises to better absorb information and form the knowledge accumulation capacity needed for incremental innovation. In addition, enterprises find it much easier to implement imitation innovation as well as improvement innovation if they absorb information of related products and technologies, which is more similar to the characteristics of incremental innovation.

With the value chain optimization effect, the specialized division of labor between domestic and foreign trade sectors achieve the accumulation of human capital and improve the ability of independent innovation. Empirical results also show that under certain conditions, human capital has a significant positive impact on radical innovation (Benhabib and Spiegel, 1994; Subramaniam and Youndt, 2005). In addition, this specialization also accelerates the accumulation of knowledge products and R&D investment, strengthening R&D as well as the innovation capacity of enterprises (Cohen and Levinthal, 1989). Companies are not required to provide completely different products or services under incremental innovation conditions, but great emphasis is put on the use of existing knowledge and skills. The equalized development of the trade sectors enhances the ability of enterprises to allocate and integrate existing resources, thus furthering incremental innovation. Figure 1 illustrate and conclude the analysis above.

Empirical tests

Data and variables

Panel data from 31 provinces and regions in China from 2006 to 2015 were used to study how domestic and foreign trade linkage affect technological innovation and how trade specialization and trade equalization affect different types of innovation. The raw data is from the website of the National Bureau of Statistics (http://www.stats.gov.cn/). The time span of the data is 10 periods (1 year each); each period includes 31 observations. The total number of observations is 310.

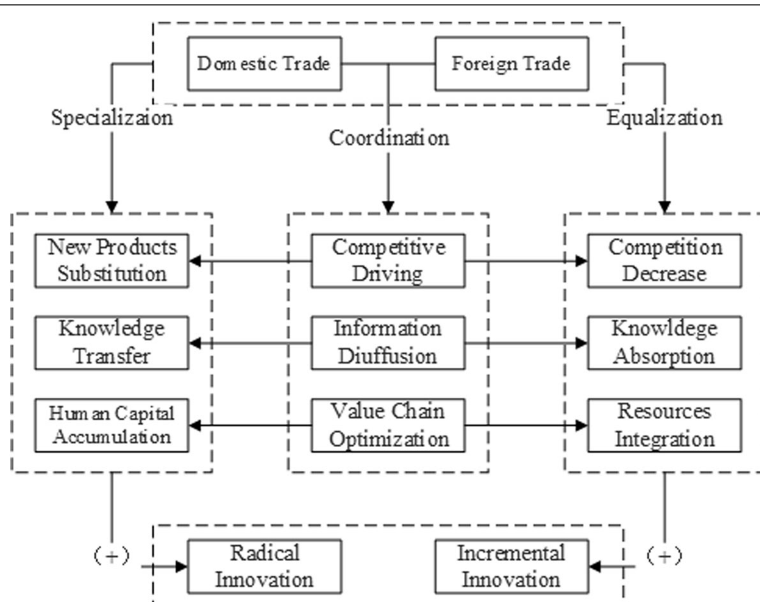

Fig. 1 The Effect of Coordinated Development of Trade on Types of Innovation

Dependent variable

The dependent variable is the level of technology innovation measured by the number of patents. According to the provisions of the Patent Law of the People's Republic of China (Chapter 2, Article 22), a patent has the characteristics of novelty, creativity and practicability compared with existing technology, which is in line with the meaning of technological innovation. The number of patents is usually selected to measure technological innovation in the existing studies (Garcia et al., 2013). Statistics related to patents in China include the number of patent applications and that of patents grants. Patent grants are generally granted for 30% to 60% of the applications. A patent may be granted a year or more after the application. In view of the correspondence of time between the dependent and independent variables, the number of patent applications will better reflect the effect on technological innovation on domestic and foreign trade coordination of the current period rather than the previous periods. In addition, since annual fees are required if a patent is granted, patent grants may be affected by bureaucratic factors (Tan et al., 2014). Thus, patent applications will more truly reflect the level of innovation. Therefore, in this paper, the number of annual patent applications in regions is selected to measure the level of technological innovation in the main empirical model, and the number of patent grants is used in the robustness test.

Different types of patents represent different types of technological innovation. China's patents are divided into invention patents, patents for utility models, and patents for designs. According to the relevant provisions of the Patent Law, the invention patent refers to a new technical method proposed for a product, the method or its improvement. The patent for utility models refers to new and practical technical methods pertaining to the shape and structure of a product, while the patent for designs refers to new designs pertaining to the beauty and industrial utilization related to the shape, pattern, etc. of a product. Therefore, the invention aspect of the patent not only involves the improvement of the product itself, but also involves the underlying technology and method of innovation, which is the basis of the formation of technology platforms and the implementation of independent innovation. In the patent application process, the invention patent has the highest requirements among the three kinds of patents. Patents for utility models are mainly for improving the product itself, including the shape, structure and function, etc. Patents for designs only focus on the appearance of the product and generally do not involve the actual function of the product, so this kind of improvement is often mainly pertaining to imitation innovation. In practice, the difficulty of applying for patents for designs and utility models is relatively low. Based on the definitions and descriptions in China's Patent Law for various types of patents and the discussions in existing studies (Tan et al., 2014; Tong et al., 2014; Li and Zheng, 2016), this paper defines the invention patent as a radical innovation, while the patent for designs and patent for utility models are defined as incremental innovations.

Independent variable - equalization trade

The core independent variable is the coordinated development of domestic and foreign trade, which includes specialized and equalized development of the two sectors, similar to two sides of a coin. The measure of equalized development is discussed first. Due to the lack of direct statistical data, the variable needs to be built specifically according to the meaning of equalized development. The specific formula is as follows: Based on the developing level and contrasting relationship of domestic trade and foreign trade, the linkage in a regional market between them can be divided into the following three states. (a) State I: This indicates equalized development when domestic and the foreign trade are both highly developed. (b) State II: This indicates specialized development if domestic trade is developed but foreign trade is relatively underdeveloped or the opposite case occurs. (c) State III: This refers to the situation where foreign trade and domestic trade are less developed. State I and State II represent the aforementioned trade coordinations, while State III is not relevant to this paper. These different states are summarized in Table 1. What the paper attempts to test in the empirical section is that State I (equalized development) is relatively more conducive to incremental innovation, while State II (specialized development) is relatively more conducive to radical innovation.

In order to describe the degree of coordinate development between domestic and foreign trade with continuous variables, this paper adopts the method of proportion difference to construct the linkage indicators, referring to the difference between the proportions of domestic trade activities in a certain region in the whole country's domestic trade and that of international trade activities. The calculation formula is as follows:

$$Trade_{it} = \left[1 - \sqrt{\left(\frac{R_{it}}{\sum_i R_{it}} - \frac{E_{it}}{\sum_i E_{it}}\right)^2}\right] \times 10000.$$

Among these, R_{it} represents the total retail sales of consumer goods of the region i in year t, and E_{it} represents the total import and export volume of the region i in year t. When a region's domestic trade and foreign trade have a higher or lower proportion at the same time, $Trade_{it}$ is larger (State I and State III), and when the trade volume of a particular trade sector is higher and that of the other is low, $Trade_{it}$ will be smaller (State II). However, if the empirical results show that the independent variable *Trade* has a positive effect on technological innovation, it implies two entirely distinct numerical adjustment directions. One is to promote the development of the trade sector with the lower proportion, making the proportions of the two sectors both reach a high level. The other is to restrain the development of the trade sector with the higher proportion so that the trade proportions of the two sectors are at a low level. The adjustment directions mentioned above can increase the value of *Trade*, but only the first scenario conforms to the real meaning of equalized development. The second scheme is not in line with policy practice. Nevertheless, the two development directions cannot be compared according to the empirical results based on the index *Trade*. To this end, this study further uses the indicator $Trade^1$ from another perspective to reflect the linkage effect of the development of domestic and foreign trade:

$$Trade^1{}_{it} = \left(\frac{R_{it}}{\sum_i R_{it}} + \frac{E_{it}}{\sum_i E_{it}}\right) \times \left[1 - \sqrt{\left(\frac{R_{it}}{\sum_i R_{it}} - \frac{E_{it}}{\sum_i E_{it}}\right)^2}\right]^2 \times 10000. \quad (1)$$

Table 1 States of trade coordination

State I: Coordination-equalization	State II: Coordination-specialization	State III: Relatively low degree of coordination
Developed domestic trade as well as foreign trade	Developed domestic trade and underdeveloped foreign trade, or developed foreign trade and underdeveloped domestic trade	Underdeveloped domestic trade and foreign trade

When domestic and foreign trade in a region reach a relative high level in the whole country, $Trade^1$ value is larger (State I). If both of the two sectors account for a low percentage, or one of them has a high proportion while the other occupies a relatively low proportion, $Trade^1$ has a smaller value (State II, III). Since it is impossible to determine which state has a relatively high $Trade^1$ value when the $Trade^1$ value is small, and the regression analysis based on the conditional mean is still unable to give a definite answer,[2] this study introduces quantile regression into our research. Combining values of *Trade* with $Trade^1$ of the provinces and regions whose technological innovation are in different quantiles, the corresponding state can be identified. In general, if the regression coefficient of the higher quantile is larger than that of the lower quantile, and the coefficient of the higher quantile regression is positive, it can be said that trade equalization is more favorable for technological innovation.[3]

To summarize the above analysis, the logic of the empirical model regarding the relationship between domestic and foreign trade and technological innovation is as follows: This study compares whether State I or State II is more helpful in achieving radical innovation or incremental innovation. By using the regression result whose dependent variable is *Trade*, this study compares the relationship between States I, III and State II. If the regression coefficient is positive, it indicates that State I or State III is superior to State II. Further, using a regression with $Trade^1$ as a dependent variable, the relationship between State I and States II, III can be compared. Assuming that the regression coefficients are positive and the regression coefficient of State I is greater than that of State III at the proper quantile, then the results show that State I is superior to State II or State III. Based on transitivity, it is not difficult to conclude that State I is superior to State II.[4]

Independent variable – Specialized development

Specialized development and equalized development are like two sides of a coin. Therefore, the aforementioned *Trade* and $Trade^1$ also measure the specialized aspect of coordinate development of domestic and foreign trade. Only under the condition that there are constraints of the production possibility frontier, the tradeoff of specialization and equalization between domestic and foreign trade exists.

As a result, the development level of the trade sector also needs to be taken into account. In other words, assuming that Province A has a higher degree of specialization and relatively more developed trade sectors, while Province B has a higher degree of equalization and less developed trade sectors than A, the results show that Province A has a higher level of technological innovation than B. Considering the positive effect that the development of trade sectors may have on technological innovation, it is difficult to determine whether this is due to the specialization of the trade sector or the development of the trade sector itself. Therefore, it is only when the development level of trade in specialized-trade areas is equal or inferior to equalized-trade areas that one can conclude that specialization is more conducive to technological innovation than equalization, and vice versa.

Therefore, the key to the construction of indicators is to identify two types of provinces mentioned above. Specifically, this study further compares the levels of domestic and international trade in different provinces and regions based on $Trade^1$ and *Trade*, which can identify equalized-trade provinces. If (a) the provinces of trade equalization are equally or less developed than the specialized provinces and (b) one can identify these provinces through different quantiles and (c) the coefficient of equalized provinces at the proper quantile is greater, it means that the equalization is more conducive to technological innovation. On the contrary, if the specialized provinces with higher coefficients are equally or less developed than the equalized provinces, it shows that the specialization is more favorable to technological innovation.

To summarize the empirical process, the key point is identifying trade equalization and trade specialization under a limited amount of resources. We construct two indicators and use traditional regression and quantile regression. They distinguish trade equalization and trade specialization at different development stages, which implies a certain amount of resources allocated to different sectors.

Control variable

The indicator of GDP per capita which reflects the overall characteristics of the region's economy is added to the regression since provincial panel data are used in the paper. Considering that the analysis of this paper focuses on the trade sectors, the indicator of wholesale and retail profit representing the industry features is also included in the regression. As well, foreign direct investment has a technology spillover effect and government expenditure affects private investment in R&D. So we also add these variables in the regression. At the same time, the fixed effect model and the time control variables are used to control other factors that may have partial correlation effects. Detailed variable settings are listed in Table 2, and the results of the descriptive statistical analysis are shown in Table 3.

Model specification and empirical tests

According to these variable settings, the basic model of this paper is set as follows: $Patent_{it}$ indicates the number of annual applications (radical innovation or incremental innovation) of different types of patents in provinces and regions. $Trade_{it}$ represents the coordination of domestic and foreign trade based on the above formula. Z_{it} represents the set of control variables:

Table 2 Dependent and independent variables

Variable	Label	Calculation Method
Patent	Total Patents	Number of Patents Accepted, Domestic (Item)
Invention	Invention Patents	Number of Invention Patents Accepted, Domestic (Item)
Utility	Patents for Utility Models	Number of Patents for Utility Models Accepted, Domestic (Item)
Design	Patents for Designs	Number of Patents for Designs Accepted, Domestic (Item)
Trade	Trade Coordination	Calculation by the Equation Mentioned above
$Trade^1$	Trade Coordination	Calculation by the Equation Mentioned above
PGDP	Economy Development	Gross Regional Product (100 Million Yuan)/ Resident Population (Year-end) (10,000 Persons)
Profit	Trade Development	Profits from Principal Business of Enterprises above Designated Size of Wholesale and Retail Trade (100 Million Yuan)
FDI	Foreign Direct Investment	Registered Capital of Foreign Funded Enterprises/ Gross Regional Product
Govern	Government Expenditure	Local Governments General Budgetary Expenditure/ Gross Regional Product

Table 3 Descriptive statistics

Variable	Observations	Mean	Standard Error	Min	Max
Patent	310	45,205	75,454	89	504,500
Invention	310	13,873	22,914	21	154,608
Utility	310	17,291	26,076	21	154,281
Design	310	14,041	31,799	28	255,474
Trade	310	9746	309.2	8167	9999
Trade1	310	572.8	620.2	13.21	2772
PGDP	310	3.61	2.12	0.634	10.69
Profit	310	7695	10,751	15.30	60,415
FDI	310	0.244	0.186	0.084	1.346
Govern	310	5.424	7.478	0.764	75.03

Data Source: *NBS* (National Bureau of Statistics of the People's Republic of China), http://www.stats.gov.cn/

$$Patent_{i,t} = \beta_1 Trade_{i,t} + \beta_4 Z_{i,t} + \varepsilon. \quad (2)$$

As described in the variables setting section, this paper further uses $Trade^1$ as the independent variable and the number of patent applications as the dependent variable for panel quantile regression. Compared with the mean regression, the quantile regression can select any quantile to perform regression analysis (Koenker and Bassett, 1978). This study uses the Koenker (2004) method to perform the panel quantile regression with a fixed effect, while the Bootstrap method is used for the estimate of standard error. The model is set to be:

$$Patent_{i,t} = \beta_1 Trade^1{}_{i,t} + \beta_4 Z_{i,t} + \varepsilon. \quad (3)$$

The problem pertaining to the comparison of the coefficient values of $Trade^1$ at the higher and lower quantiles is how to determine the higher and lower quantiles. In line with the previous analysis, $Trade^1$ at the higher quantile should correspond to a higher *Trade* value than that of the lower quantile, which means that the degree of linked development of domestic and foreign trade continues to increase. The total amount of imports and exports and the total retail sales of consumer goods should also improve, which means that both domestic and foreign trade have developed; that is, equalized development described in this paper is obtained. Tables 4 and 5 compare the average ranking of coordination indicators of domestic and foreign trade (*Trade*, $Trade^1$), the total import and export volume (*E*), and the total retail sales of consumer goods (*R*) when the various types of patent applications are in different intervals.

In Table 4, with the increase in the number of patent applications, the rankings of total import and export volume (*E*), the total retail sales of consumer goods (*R*) and

Table 4 The mean value of variables in different intervals of invention patents

	80–90	70–80	60–70	50–60	50–40	40–30	30–20	10–20	1–10
Trade	28.7	23.0	18.5	21.3	18.4	14.8	15.0	10.9	9.8
R	2.7	5.1	12.4	13.7	15.2	12.5	20.4	22.2	22.7
E	4.5	5.6	11.9	13.9	16.2	13.7	19.3	25.6	22.4
$Trade^1$	3.0	4.7	12.1	12.7	14.4	12.6	20.1	22.5	24.4

Data Source: *NBS* (National Bureau of Statistic of the People's Republic of China), http://www.stats.gov.cn/

Table 5 The mean value of variables in different intervals of patents for utility models and patents for design

	80–90	70–80	60–70	50–60	50–40	40–30	30–20	10–20	1–10
Trade	25.3	24.4	22.3	16.7	18.7	17.9	13.6	10.6	11.9
R	2.6	7.7	9.5	9.6	17.7	14.3	20.2	21.6	23.5
E	5.0	10.6	9.7	10.0	15.2	15.0	20.7	26.0	19.6
$Trade^1$	2.2	7.2	9.5	10.1	15.5	14.8	20.2	22.9	23.7

Data Source: *NBS* (National Bureau of Statistic of the People's Republic of China), http://www.stats.gov.cn/

$Trade^1$ continue to rise while there is a decline in *Trade*. The ranking of *Trade* increases when the number of patent applications is in the interval of 60% to 70%, and then decreases in the interval of 70% to 90%. The $Trade^1$ value in 60% to 70% represents the equalization of trade. Intervals less than 60% or more than 70% include a weak coordination of domestic and foreign trade and the specialized development of trade. Table 5 shows the ranking of variables with different quantiles after the addition of patents for utility models and designs. Like Table 4, *Trade* rankings rise and then decline in the interval of 50% to 60%. That is, $Trade^1$ in the interval of 50% to 60% represents the equalization development of trade, while an interval of more or less than 50% means that the degree of trade coordination is weak. An interval of more than 60% refers to the situation of specialization development of trade. This study, therefore, uses 20%, 40%, 60%, and 80% as the quantiles of the quantile regression. $Trade^1$ value of the regression at the 60% quantile should be positive and higher than that at the 20% and 40% quantiles if the equalization of trade really contributes to the improvement of innovation.

In terms of the specialized development of trade, it indicates that specialization is more helpful for technological innovation than equalization if the regression coefficient of the 60% quantile is less than that at the 40% and 20% quantiles. Since the development level of trade sectors (*R* and *E*) at 40% and 20% is comparable or lower than the 60% quantile, and if the regression coefficient for the 60% quantile is smaller than that of 40% and 20%, it means that equalization of trade squeezes the resources for the specialized development of the trade sector. This leads to an increase in the degree of equalized development. After the improvement of the trade sector, the positive role of trade coordination in technological innovation is otherwise weaker. In the case of trade equalization, it is noted that the development level (*R* and *E*) at 80% is equal to or higher than that at the 60% quantile. If the regression coefficient of the 60% quantile is greater than that of 80%, one can conclude that equalization of trade makes up for the deficiency of trade development and is more conducive to the improvement of technology innovation compared with specialization of trade.

To control the heterogeneity of different provinces and regions, this paper has adopted the fixed effect model to estimate the baseline effect, and the time dummy variable is used to control the period fixed effect. Tables 6 and 7 show the related regression results, among which the number of total patents, invention patents and the sum of the latter two are regarded as the dependent variables from the first column to the third column, respectively. The Hausman test results also support the fixed effect model. The Modified Wald test and the Pesaran test show that there are heteroscedasticity and cross-sectional dependence, and that utilizing the commonly used clustering robustness error makes it difficult to obtain a

Table 6 The impact of trade coordination: benchmark regression

	1-Patent	2-Invention	3-Utility + Design
PGDP	12546***	5446***	7100***
	(2224)	(1612)	(738.9)
Profit	3.372***	1.077***	2.295***
	(0.416)	(0.156)	(0.266)
FDI	188.0*	154.1*	33.83
	(95.51)	(81.74)	(54.63)
Govern	−73380***	−32359**	−41021***
	(14450)	(11185)	(5088)
C	−9124**	−7005**	−2120
	(2920)	(2337)	(1311)
Individual Fixed	Yes	Yes	Yes
Driscoll–Kraay SE	Yes	Yes	Yes
Within R^2	0.5582	0.5782	0.4815
F–Test	223.1***	461.5***	193.7***
Hausman Test	11.53***	21.62***	7.06*
Modified Wald Test	2.0E + 4***	5.1E + 4***	4.2E + 4***
Pesaran Test	11.93***	12.49***	9.12***

Standard Error appears in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$
Hausman Test H_0: Random Effects Model is valid
Modified Wald Test H_0: The variances are identical
Pesaran Test H_0: There is no cross-sectional dependence

Table 7 The Impact of trade coordination: fixed effects model

	1-Patent	2-Invention	3-Utility + Design
Trade	257.9***	85.12***	172.8***
	(35.66)	(19.71)	(29.22)
PGDP	11906***	5274***	6632***
	(1600)	(1378)	(721.7)
Profit	2.616***	0.826***	1.790***
	(0.354)	(0.176)	(0.213)
FDI	354.3***	194.9**	159.4
	(84.04)	(78.08)	(87.39)
Govern	−64673***	−30702***	−33971***
	(8390)	(8533)	(6035)
C	−2.5E + 6***	−8.3E + 5***	−6.6e + 5***
	(347247)	(192594)	(80249)
Time Control Variable	Control	Control	Control
Individual Fixed	Yes	Yes	Yes
Driscoll-Kraay SE	Yes	Yes	Yes
Within R^2	0.6215	0.6309	0.5461
F-Test	67.24***	340.7***	22.02***
Hausman Test	24.17**	132.2***	16.39[a]
Modified Wald Test	6.5E + 4***	2.7E + 4***	4.1E + 4***
Pesaran Test	6.97***	9.94***	4.65***

Standard Error appears in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. The H_0 of the tests are the same as in Table 6
[a]Although the Hausman test does not refuse the H_0, we still use the fixed effect to control the individual heterogenicity

consistent estimation result. It is a better choice to use the Driscoll-Kraay standard error to modify. In addition, the Driscoll-Kraay standard does not impose restrictions on the number of samples, which has a better performance when the number of observations is small (Driscoll and Kraay, 2006). Table 6 shows the results only including the control variables. The *Trade* indicator is added as the independent variable in Table 7. It indicates that trade equalization has a significant positive effect on technological innovation, and that the adjusted R^2 is improved (0.05–0.1). As stated earlier, the regression does not recognize the situation where both domestic trade and international trade are higher or lower at the same time. Therefore, further tests in virtue of a quantile model with $Trade^1$ as the independent variable is needed.

Tables 8 and 9 show the results of quantile regression using $Trade^1$ as an independent variable. As mentioned earlier, this paper selected 20%, 40%, 60% and 80% as regression quantiles. Equalization and specialization of trade show different characteristics for different types of innovation. Among them, the regression coefficients for the invention patent declines successively in the interval from 20% to 80%, indicating that specialized trade has significantly improved radical innovation.

The results of the regression taking patents for utility models and designs as the dependent variables are shown in Table 9. The regression coefficient of the 60% quantile is greater than that of 20%, 40% and 80%, indicating that equalization trade is conducive to improving incremental innovation. In particular, the regression coefficient of the 60% fraction is greater than 80%, which means that with the consideration of resource constraints, equalization trade has made up for the inherent disadvantage of insufficient development of domestic trade as well as international trade. Also, some areas where domestic or foreign trade development is not at the forefront can enhance incremental innovation through trade equalization. In other words, when there is imbalance between the domestic and the foreign trade sector, policies that give priority to promoting a slower-growing trade sector are more conducive to incremental innovation than policies that provide more support for faster-growing sectors.

Table 8 The impact of trade coordination: fixed effect panel quantile (radical innovation)

	1–20% Invention	*2–40% Invention*	*3–60% Invention*	*4–80% Invention*
Trade¹	5.946***	5.902***	4.760***	5.606
	(1.032)	(1.752)	(2.737)	(7.144)
PGDP	220.8	70.03	665.6	1287*
	(157.3)	(276.0)	(419.3)	(735.9)
Profit	0.762***	1.093***	1.189***	1.728***
	(0.105)	(0.150)	(0.162)	(0.355)
FDI	−159.3	−219.6	−124.8	−5.062
	(144.6)	(189.9)	(194.2)	(153.3)
Govern	227.4	279.9	−718.0	−197.0
	(843.1)	(561.1)	(851.4)	(2266)
C	−3543***	−2655***	−3210***	−4155*
	(847.1)	(906.8)	(1126)	(2586)
Time Control Variable	*Control*	*Control*	*Control*	*Control*
Individual Fixed	Yes	Yes	Yes	Yes

Standard Error appears in parentheses adjusted by 1000 times Bootstrap. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$
The score of Lambda is the default 1

Table 9 The impact of trade coordination: fixed effect panel quantile (incremental innovation)

	1–20% *Utility + Design*	*2–40%* *Utility + Design*	*3–60%* *Utility + Design*	*4–80%* *Utility + Design*
Trade[1]	27.15***	34.81***	42.49***	48.34***
	(4.794)	(8.390)	(11.47)	(22.08)
PGDP	1197***	1208*	226.2	262.2
	(400.6)	(733.1)	(749.6)	(883.6)
Profit	0.404**	0.660	1.616*	3.327*
	(0.171)	(0.601)	(0.833)	(1.772)
FDI	−−291.5	−368.6	−27.25	22.67
	(418.0)	(617.7)	(448.5)	(217.9)
Govern	−5626	−72.93	3244*	5799
	(4332)	(2230)	(1932)	6307
C	−11651***	−12372***	−13874***	−16447***
	(3253)	(3677)	(3647)	(5059)
Time Control Variable	*Control*	*Control*	*Control*	*Control*
Individual Fixed	Yes	Yes	Yes	Yes

Standard Error appears in parentheses adjusted by 1000 times Bootstrap. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$
The score of Lambda is the default 1

In terms of control variables, the economic development and trade sector development in the fixed effect model have a significant positive impact on innovation, which is basically consistent with the usual expectations. In the regression of panel quantile, the impact that economic development has on technological innovation is not significant at some quantiles. In addition, the signs of regression coefficients vary at different quantiles, which can be explained by the non-linear relationship between economic development and technological innovation. The existing empirical research also points out that technological innovation has a threshold effect on economic growth (Tang, 2004; Xie, 2015). This relationship is also likely to appear in the effect of economic development on technology innovation.

Robustness test

Four approaches are used to test the robustness of empirical results. One is to replace the dependent variables, the second is to discretize the independent variables, the third is to take the lag of innovation into account and the fourth is to change the measurement method of the index $Trade^1$ in the quantile regression.

Replacement of the dependent variable

In the results presented above, this paper takes the number of patent applications in each province as the dependent variables to reflect the level of technological innovation in a region. In the data released by the National Bureau of Statistics, the number of patent grants also represent the level of innovation in a region. Taking into account the large gap between patent applications and patents grants in different regions, the number of patents granted is about 30% to 60% of the number of patent applications. To avoid the influences of different selection of dependent variables, the number of patent applications is replaced by the number of patent grants as dependent variables. Control variables are consistent with the benchmark model. The regression results are shown in Table 10. The regression results are consistent with the benchmark regression after the substitute of the dependent variables.

Table 10 Robustness test: alternative dependent variables

	1–Patent	2–Invention	3–Utility + Design
Trade	129.5***	12.42***	117.1***
	(18.25)	(3.41)	(21.29)
PGDP	6314***	922.4*	5391***
	(1117)	(466.7)	(768.2)
Profit	1.859***	0.306***	1.552***
	(0.254)	(0.0726)	(0.193)
FDI	195.6***	51.82	143.8**
	(56.30)	(34.99)	(57.98)
Govern	−33408***	−4479*	−28929***
	(4871)	(2093)	(4165)
C	−1.3E + 6***	−1.2E + 5***	−1.1E + 6***
	(177241)	(33708)	(207164)
Time Control Variable	Control	Control	Control
Individual Fixed	Yes	Yes	Yes
Driscoll-Kraay SE	Yes	Yes	Yes

Standard Error appears in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. The tests are the same as in Table 6

Discretization of the independent variables

The impact of trade equalization (specialization) on technological innovation may not have a strict continuous relationship and may show some kind of interval; that is, equalization and specialization have a similar effect on innovation when the degree of these is in a certain range. Only when the equalization (specialization) continues to accumulate and breaks through the interval may it show a stronger impact. For the above considerations, the major independent variable *Trade* is discretized. From 2006 to 2013, the value of the index is between 8000 and 10,000. This study defines the value of the variable from 8000 to 8499 as 1, 8500 to 8999 as 2, and so on. After the discrete treatment, the domestic and foreign trade linkage index is divided into four ranks. As shown in Table 11, the regression results did not show any differences.

Lag of innovation

It usually takes much time for enterprises to innovate successfully so that trade coordination may affect innovation after several periods. At the provincial level, however, the sum of independent enterprises may make innovation converge to its expectation. Furthermore the hazard rate of innovation is commonly regarded as following the extreme value distribution so the extreme value may have less effect in the regression with the provincial data. Although we argue that the lag of innovation is probably not significant at the province level, we still add the first order lag and the second order lag of the *Trade* and use the finite distributed lag model. The results in Table 12 shows that trade coordination in the present period still significantly affects innovation while trade coordination in the previous period has little effect.

Change of measurement method

$Trade^1$ uses the form of sum to describe the development level of domestic and foreign trade in regions. The measurement is changed and the indicator $Trade^2$ constructed in

Table 11 Robustness Test: Discretization of Independent Variables

	1–Patent	2–Invention	3–Utility + Design
Trade	53040**	15712***	37328**
	(19456)	(4795)	(16013)
PGDP	12526***	5497***	7029***
	(2077)	(1589)	(835.7)
Profit	3.106***	0.989***	2.116***
	(0.473)	(0.194)	(0.291)
FDI	335.7***	189.8**	145.9
	(87.52)	(79.04)	(91.68)
Govern	−64342***	−30805**	−33537***
	(12109)	(10112)	(5340)
C	−2.1E + 5**	−65841***	−1.5E + 5**
	(73640)	(17662)	(61989)
Time Control Variable	Control	Control	Control
Individual Fixed	Yes	Yes	Yes
Driscoll-Kraay SE	Yes	Yes	Yes

Standard Error appears in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. The tests are the same as in Table 6

Table 12 Robustness test: the lag of innovation

	1–Patent	2–Invention	3–Utility + Design
Trade	250.6***	65.90**	184.7***
	(47.82)	(21.44)	(34.86)
L1.Trade	8.483	20.59	−12.11
	(58.51)	(17.63)	(43.12)
L2.Trade	−4.733	−19.43	14.70
	(57.54)	(17.10)	(42.70)
PGDP	12680***	5131***	7548***
	(1843)	(1448)	(748.9)
Profit	2.287***	0.788***	1.499***
	(0.565)	(0.239)	(0.334)
FDI	243.3	100.8**	142.5
	(155.8)	(41.20)	(133.6)
Govern	−59123***	−26690**	−32434***
	(12772)	(9686)	(6809)
C	−2.5E + 6***	−6.6E + 5**	−1.8E + 6***
	(474479)	(210315)	(344315)
Time Control Variable	Control	Control	Control
Individual Fixed	Yes	Yes	Yes
Driscoll-Kraay SE	Yes	Yes	Yes

Standard Error appears in parentheses. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. The tests are the same as in Table 6 the form of multiplication. In contrast to $Trade^1$, $Trade^2$ has a higher scoring penalty in areas where the development of domestic and foreign trade is unbalanced, and $Trade^2$ is relatively smaller when one proportion of the two major trade sectors is low. The specific calculation is as follows:

$$Trade^2{}_{it} = \frac{R_{it}}{\sum_i R_{it}} \times \frac{E_{it}}{\sum_i E_{it}} \times \left[1 - \sqrt{\left(\frac{R_{it}}{\sum_i R_{it}} - \frac{E_{it}}{\sum_i E_{it}}\right)^2}\right]^2 \times 10000. \quad (4)$$

Panel quantile results are shown in Tables 13 and 14. In the radical innovation, the coefficient of 40% quantile is significantly larger than that of 60% quantile and in the incremental innovation, the coefficient of 60% quantile is also significantly larger than that of 80%. These results are consistent with the previous test.

Implications and discussion of the results

Based on the total retail sales of consumer goods and the total amount of import and export, this paper constructs proxy variables that reflect the equalization and specialization of trade. Although both trade equalization and trade specialization benefit innovation, only one of them has priority for resources to be allocated since resources are limited. The results support the hypothesis that trade equalization strengthens incremental innovation more effectively while trade specialization is more beneficial to radical innovation. The coefficients of control variables in mean-value regression are consistent with the economic intuition. Though the coefficients differ at different quantiles in quantile regression, the results are still consistent with previous work which implies the nonliner relationship between control variables and innovation.

For a region where economic growth is driven by the diffusion effect of the core industry (Rostow, 1990), imitation and incremental innovation are more important. So attention should be paid to the equalized development of domestic and foreign trade. Resources should be allocated to the weaker sector and the over-persuasion for specialization of a trade sector should be avoided. The government can promote equalization of trade by means of tax preferences, supporting relevant infrastructure construction, etc. For example, if domestic trade is relatively less developed, the policy makers of the region can invest fiscal funds into constructing logistics facilities and giving preferential tolls for roads or bridges. If foreign trade needs further improvement, in contrast, export tax rebates and establishment of bonds area are then suggested. Since scientific research takes a certain period of

Table 13 Robustness test: change the indicator of trade coordination (dependent variable: radical innovation)

	1–20% invention	*2–40% invention*	*3–60% invention*	*4–80% invention*
Trade²	77.24***	69.30***	56.13	11.88
	(15.15)	(26.04)	(60.76)	(189.8)
Control Variable	*Control*	*Control*	*Control*	*Control*
Time Control Variable	*Control*	*Control*	*Control*	*Control*
Individual Fixed	Yes	Yes	Yes	Yes

Standard Error appears in parentheses adjusted by 1000 times Bootstrap. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$
The score of Lambda is the default 1

Table 14 Robustness test: change the indicator of trade coordination (dependent variable: incremental innovation)

	1–20% *Practical + Design*	*2–40%* *Practical + Design*	*3–60%* *Practical + Design*	*4–80%* *Practical + Design*
Trade^2	325.8***	544.6***	625.6***	587.5
	(81.08)	(158.4)	(233.2)	(456.3)
Control Variable	*Control*	*Control*	*Control*	*Control*
Time Control Variable	*Control*	*Control*	*Control*	*Control*
Individual Fixed	Yes	Yes	Yes	Yes

Standard Error appears in parentheses adjusted by 1000 times Bootstrap. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$
The score of Lambda is the default 1

time, the government should pay special attention to the stability, continuity and sustainability of relevant policies.

For a region where economic growth is driven by the core industry itself and leads the development of other regions (Rostow, 1990), radical innovation is more significant. In areas pursuing radical innovation, great emphasis should be put on the specialization of the trade sector, avoiding equal allocation of resources to the domestic and foreign trade sectors. On the premise of the suitable policies mentioned above, however, policy makers should focus on developing superior industries according to the characteristics of the regional economy and improve innovation, and also focus on quality rather than quantity through specialized development of trade.

Conclusions and discussions

This paper discussed the effect that trade has on technological innovation, especially from the perspective of the interaction between domestic and foreign trade. Foreign trade affects innovation from technology spillover such as imitation, competition, upstream and downstream links. The findings presented in this paper show that the coordinated development of domestic and foreign trade leads to effects on innovation mainly through the information diffusion effect, competition driving effect and value chain optimization effect. This will strengthen technology spillover, and thereby enhance technology innovation. Moreover, the coordinated development of domestic and foreign trade is classified into trade equalization and trade specialization. Trade equalization mainly promotes incremental developments, while trade specialization improves radical innovation. It is worth noting that although this paper divides technological innovation into two types (radical and incremental), it does not mean that the former is more beneficial to regional economic development than the other. Since the economic development stage and the industrial structure differ in different regions, radical innovation may fit the development needs of certain areas but be counterproductive in other areas where incremental innovation is more in line with the actual situation, and then promote the economic development in these areas.

This paper constructs proxy variables that reflect the equalization and specialization of trade. The number of patent applications is set as the dependent variable, combined with the fixed effect panel model and fixed effect panel quantile model. The paper examines the role that trade equalization or trade specialization plays in regard to different types of technological innovation. The empirical results support the theoretical predictions.

In this paper, we develop a construct named trade coordination which can be well estimated and evaluated by the empirical methods we give above. Further studies include exploring the relationship between trade coordination and other variables such as investment propensity or total factor productivity. The study of antecedent variables is also important for specific policies to improve trade coordination.

Endnotes

[1]As radical innovation usually refers to the top and advanced innovation and most innovations are not radical innovation, we should be careful of using this definition. In this paper, we do not use radical innovation to indicate the very few top innovations. We think the classification of radical innovation and incremental innovation implies that innovations have two main types which differ significantly. One is the invention and break of the present technology path. The other is the improvement and modification along the present technology. We use radical innovation to indicate the former and incremental innovation to indicate the latter.

[2]Consider the following situation: *Trade* = A in State I, *Trade* = B in State II and *Trade* = C in State III, assuming that A > B > C. Then the conditional mean regression results in the trend in an average sense. The positive regression coefficient probably only means that State II is more conducive to innovation than State III.

[3]The actual situation may be more complicated; a detailed discussion of the quantile can be found in the model setting section.

[4]Consider the following three cases: First, the conditional mean regression shows that State I is superior to State II and that proposition is correct directly. Second, the quantile regression shows that state I is superior to state II, and the proposition is correct. Thirdly, the conditional mean regression shows that State III is superior to State II and the quantile regression shows that State I is better than State III. One can then conclude that State I is better than State II. As a result, the proposition holds through the transitivity.

Acknowledgements
We gratefully acknowledge Prof. Li Jiatao from the Hong Kong University of Science and Technology. He gave us many suggestions for constructs definition and empirical models. We also express our gratitude to discussants at the 2017 FBR symposium who gave us inspiration for theory hypothesis and methodology.

Funding
Projects of the National Social Science Foundation of China (16AJY016). Prof. Xiaodong Wang.

Availability of data and materials
The dataset supporting the conclusions of this article is available from the NBS (National Bureau of Statistics of the People's Republic of China), http://www.stats.gov.cn/.

Authors' contributions
LX put forward the theme of the paper, carried out the study of theoretical framework and mechanism analysis, and drafted the manuscript. SW performed the statistical analysis, participated in the design of the study and drafted the manuscript. XW participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

Publisher's Note

Received: 15 June 2017 Accepted: 19 September 2017
Published online: 26 September 2017

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