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# Trade Facilitation, R&D Innovation, and Export Sophistication of Manufacturing Industries: Evidence from Russia and Central-Eastern European Countries

**Abstract:** This paper calculates the trade facilitation index and manufacturing export sophistication of Russia and Central and Eastern European countries from 2003 to 2017, and examines the impact of trade facilitation and R&D innovation on manufacturing export sophistication. The study found that the export sophistication of labor-intensive industries continues to decrease, the export sophistication of capital and technology-intensive industries continues to increase, while the export sophistication of traditional resource-based heavy industries is stable. In addition, trade facilitation and R&D innovation have significantly contributed to the export sophistication of Russia, Central and Eastern European countries, especially the manufacturing industry after the 2009 financial crisis. For Central European and European Union member states, the impact of trade facilitation and R&D innovation on export sophistication is significantly greater than that of Eastern European and non-EU member states. The promotion of heavy, heterogeneous, medium and high-tech industries is obviously stronger than that of light, homogeneous and low-tech industries. In addition, the moderating role of trade dependence cannot be ignored. Trade facilitation and R&D innovation have a significant non-linear impact on export sophistication.

**Keywords:** Trade Facilitation, Export Sophistication, Manufacturing, R&D Innovation, Russia, Central and Eastern Europe

## 1. Introduction

In recent decades, the exports of developing countries such as Russia and Central and Eastern Europe in Eurasia have made significant progress, and their status in the international market has also been improved. From 2003 to 2017, the average annual growth rate of exports reached 10.7%. Among them, Russian exports were US \$0.13 trillion in 2003 and US \$0.36 trillion in 2017, with an average annual growth rate of approximately 10.3%. The export value of Central and Eastern European countries was 0.02 trillion U.S. dollars in 2003 and increased to 0.05 trillion U.S. dollars in 2017, with an average growth rate of 9.7%. However, the world is still in an era of weakening demand and in-depth industrial adjustments. Under the dual influence of the European sovereign debt crisis and trade protectionism, the traditional "massive" trade model based on the expansion of export flows has been developing in Europe and Asia. The trade model abused by the economy cannot be sustained and will inevitably become an increasingly severe obstacle to export development.

As the academic community pays more attention to the quantity in the field of international trade to quality, export sophistication or export technological sophistication, an indicator for evaluating a country's industrial commodity production and export capacity have attracted attention from related fields. The capacity theorem holds that economic growth is a process of achieving the sophistication of a country's production and export technology. The ability to produce high-precision products is a key factor in determining economic prosperity or persistent poverty, and has an

important impact on the economic development of a country or region (Hidalgo, et al., 2007; Hausman & Hidalgo, 2010; Li, et al., 2015).

## **2. Literature review**

The study of export sophistication in the field of international economics has two directions. First, the change of export sophistication and international comparison research. Lall, et al. (2006) constructed a technological sophistication index based on the income level of exporting economies, calculated the technological sophistication scores at 3-digit and 4-digit levels, and tested the correlation between the index and the existing product technology classification. Rodrik (2006) evaluated China's export sophistication in 2000, and he found that China's export sophistication far exceeded its economic development level. Schott (2008) examined the technological structure of export commodities from developing economies from the perspective of OECD members, and found that the similarities between the two groups gradually approached. Qiu, et al. (2012) used the trade data of major countries in the world to calculate the export technological sophistication of China's 2-digit manufacturing industry from 2001 to 2009. The second is the research on the impact of export sophistication. Scholars have conducted empirical research from different perspectives. Liu, et al. (2014) proposed a new framework for global value chain evaluation based on the dual participation structure of products and functions, and examined the impact of global value chain participation, structure and value sources on export sophistication. Fan, et al. (2018) research shows that cultural diversity affects export sophistication by increasing the degree of economic heterogeneity. Lapatinas (2019) believes that after controlling for potential covariates, the internet has a positive impact on the sophistication of exported products. Banerjee & Nayak (2017) showed that the increase in the per capita stock of foreign direct investment has a positive impact on the quality of exports from developing countries.

In the study of trade facilitation, scholars have achieved fruitful results from a diversified perspective. A large number of documents have conducted in-depth discussions on the impact of trade facilitation. Wang & Li (2015) investigated trade facilitation and export diversity. It is found that the promotion of trade facilitation is conducive to the increase of the diversity of export products. Brooks & DAVIS (2019) found that the impact of credit friction on trade facilitation depends on the endogenous nature of debt restrictions and the response to profit opportunities. Dissanayake, et al. (2019) examined the relevant macroeconomic and sectoral impacts and found that regional trade facilitation is not an easing option to improve the welfare of Sri Lanka and Bangladesh. There are many other interesting factors that are potentially associated with trade facilitation, such as child mortality (Olper, et al., 2018), shifting of environmental burdens (Kolcava, et al., 2019), and trade dependence (Osakwe, et al., 2018). In addition, some scholars are committed to the construction of trade facilitation, including specific internal indicators of trade facilitation as a whole. Estrada (2004) proposed a new trade analysis model to evaluate any country's trade facilitation changes and stages by introducing four basic stages in the implementation of the methodology. Linde & Pescatori (2019) investigated the trade flow effect of import tariffs and export subsidies of the same scale to illustrate the macroeconomic costs of trade wars. Cull, et

al. (2015) described a new microfinance institution's business environment quality index, and verified the index by linking it and its subcomponents with microfinance results.

Summarizing the existing literature, it is not difficult to find that none of the above-mentioned related studies has involved the impact of trade facilitation on export sophistication. Based on the perspective of trade facilitation, scholars mainly focus on the analysis of trade flow scale, trade structure and trade multiple margins, without considering the correlation between trade facilitation and export sophistication. In addition, from the perspective of country studies, most studies related to the economic and trade relations of transition economies (such as Russia and Central and Eastern European countries) focus on trade flows, trade complementarity and competitiveness, but lack the quality or sophistication of their exports. Therefore, this paper focuses on the impact of trade facilitation on the export sophistication of transition economies.

### **3. Theoretical mechanism**

It is worth noting that, unlike export trade flows, the evolution of trade facilitation does not directly affect export sophistication at the national and industrial levels, but triggers changes in some ways and affects export sophistication. Therefore, when studying various factors that regulate the correlation between trade facilitation and export sophistication, scholars have conducted in-depth research on its theoretical mechanism and influence path. Wang & Li (2015) believed that trade facilitation can reduce the fixed costs of enterprises engaged in trade business and lower the productivity threshold that meets export standards, thereby promoting export diversification and export sophistication. Bas & Kahn (2015) examined the impact of import trade facilitation on the prices of imported inputs and export products, indicating that exogenous tariff cuts will reduce the cost of imported high-quality intermediate products in developed countries, and import equipment for domestic exports. Intermediate products will promote quality upgrades. Jiang & Zhang (2008, 2014) believe that the "technological spillover" effect after the host country absorbs high-tech foreign direct investment will produce positive externalities to export sophistication. Ying, et al. (2016) pointed out that the country participates in the international vertical specialization of labor through processing trade, import of intermediate goods, etc., to induce technological spillover effects, and learn through "learning by doing" effect to achieve the goal of increasing export sophistication.

From the current research, there are two potential paths for the impact of trade facilitation on export sophistication, one is intermediate goods imported by developed countries, and the other is foreign direct investment. For the former, imported imports and trade facilitation will lead to the "technological spillover" effect of imported intermediate products, improve trade efficiency, provide convenience for export enterprises to obtain a large number of advanced technology imported intermediate products, and help them accelerate R&D and innovation capabilities. Ultimately, the sophistication of national and industrial exports will be increased, and the trade pattern will be transformed from "quantity-oriented" to "quality-oriented". For the latter, foreign direct investment uses the "learning by doing" effect produced by the implementation of trade facilitation, which can shorten the negotiation time between

export companies and foreign partners, reduce investment costs, and improve local business models for companies located in export regions provide convenience, make full use of the comparative advantages of related industries, and absorb advanced technology in foreign direct investment, thereby increasing productivity and increasing the level of export sophistication. This paper draws on the theoretical analysis framework of Sterlacchini (2008) for follow-up empirical analysis, and further examines the impact of trade facilitation on the export sophistication of transitional economies.

#### 4. Index measurement

##### 4.1 Measurement for trade facilitation

This section focuses on measuring trade facilitation indicators. The academic circles have not yet reached a consensus on the definition of trade facilitation. According to the World Trade Organization (WTO), the concept of trade facilitation is: "The data flow of goods that need to be collected, transmitted and processed in international trade involves simplified and coordinated activities, conventions and procedures". The World Customs Organization (WCO) defines it as "using modern technology and technics to eliminate unnecessary trade restrictions, and internationally coordinated measures to improve the level of supervision." In view of the breadth and inconsistency of the definition of trade facilitation, the Asia-Pacific Economic Cooperation (APEC) "Trade Facilitation Action Plan" identified four aspects of trade facilitation, customs procedures, standards and coordination, business flows, finance and e-commerce. Therefore, this paper refers to the method of Kong & Dong (2015) to evaluate the trade facilitation of Russia and Central and Eastern European countries. In addition, taking into account the latest provisions of the Trade Facilitation Agreement issued by the WTO and the characteristics of the economic development of the transitional economies Russia and Central and Eastern European countries, this paper draws on the research of Fang & Zhu (2013) and Liu, et al. (2018), introduce four first-level indicators of port efficiency, customs environment, supervision environment and e-commerce. At the same time, considering the availability of data, this paper introduces 8 secondary indicators such as port infrastructure quality, transportation infrastructure quality, logistics quality, burden of customs procedures, customs clearance efficiency, import turnover time, weighted average applicable tariffs for industrial products, and information and communication technology, derived from the World Bank World Development Index Database (see *Table 1*).

**Table 1 Trade facilitation indicators**

First-level indicator	Second-level indicator
(1) port efficiency	(1) quality of port infrastructure (2) quality of transportation infrastructure (3) quality of logistics
(2) customs environment	(1) burden of customs procedure (2) efficiency of customs clearing (3) time of import turnover
(3) regulatory environment	(1) weighted-average applied tariffs of industrial commodity

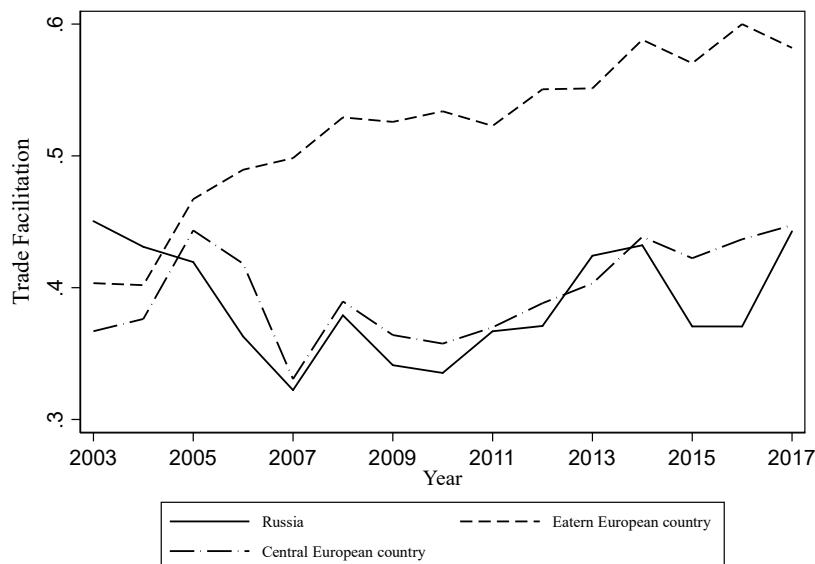
(4) e-commerce

(1) information and communication technology

Note: There are many indicators involved in trade facilitation, and some scholars have introduced different indicators for their research. Since there are a large number of missing values in the World Development Indicators database of Russia and Central and Eastern European countries, the inconvenient introduction of missing value indicators will lead to misleading empirical results. Therefore, 8 relatively complete secondary indicators are introduced to construct comprehensive indicators. Enough to clearly illustrate the basic change of trade facilitation in the sample countries.

In this paper, the aggregative indicator will be constructed with entropy valuation method, which includes five steps. To the first, use the denormalization formula for comparability,  $T_{ct} = [I_{ct} - \min(I_c)] / [\max(I_c) - \min(I_c)]$  to transform linearly original values of all indicators to values range from zero to one, where  $I_{ct}$  refers to the representative indicator  $c$  in year  $t$ . Then calculate the ratio of  $T_{ct}$  of whole period,  $H_{ct}$ . Secondly, evaluate the information entropy,  $E_c$ , by utilizing the formula  $E_c = -d \sum_{t=1}^m [H_{ct} \ln(H_{ct})]$ , where  $d = 1 / \ln(m)$ ,  $m$  denotes sample time span,  $m = 15$  here. Thirdly, calculate redundancy,  $D_c = 1 - E_c$ . Fourthly, calculate the weight of indicators,  $W_c = D_c / \sum_{c=1}^N D_c$ , where  $N$  is the number of indicators,  $N = 8$  here. Fifthly, integrate second-level indicators into the aggregative trade facilitation indicator,  $ETI_t = \sum_{c=1}^N W_c T_{ct}$ .

From the perspective of countries or regions, trade facilitation indicators are divided into Russia, Eastern European countries and Central European countries. The change of trade facilitation is shown in *Fig. 1*.



**Fig. 1** The annual change of trade facilitation

It can be seen from *Fig. 1* that Russia's trade facilitation has experienced considerable fluctuations. It was in a downward change before 2007, slowly declined after 2009, and

fell again in 2004, and then rebounded. The trade facilitation of Central European countries fluctuates greatly, showing an upward change before 2005, and its trajectory is roughly similar to that of Russia. Compared with the former, the trade facilitation of Eastern European countries fluctuates more slowly, and it basically shows an upward change during the sample period.

#### 4.2 Measurement for export sophistication

Scholars at home and abroad have made unremitting efforts to calculate export sophistication and developed a variety of measurement methods. Archibugi & Coco (2005) suggested a technological achievement index. Lall, et al. (2006) introduced a commodity export sophistication index based on the assumption of the technological content of commodities, and calibrated the index by changing the assumptions (Du & Wang, 2007). Schott (2008) developed a technological similarity index based on the fact that most of the high-tech innovation countries come from high-income economies, by comparing the structure of export commodities with OECD countries. Hausmann, et al. (2007) believed that traditional methods had technology and sophistication problems, and developed export sophistication based on national income levels. This paper draws on the method of Hausmann, et al. (2007), based on the United Nations Comtrade database, to determine the 195 countries in the sample period from 2003 to 2017, and based on the third revision of the Standard International Trade Classification (SITCRev.3), to determine the 2-digit level 203 manufacturing products. The detailed export at the country and commodity level was adjusted to the unchanged US dollar price in 2005, so that the constant price would yield. First, in order to evaluate the export sophistication of a specific manufacturing product,  $k$ , the export sophistication formula is:

$$PRODY_p = \sum_c \left[ \frac{X_{cp} / X_c}{\sum_c (X_{cp} / X_c)} pcgdp_c \right] \quad (1)$$

Where  $k$  denotes the manufacturing commodity at 3-digit in SITC (Rev. 3),  $c$  denotes the sample country,  $X_{cp}$  and  $X_c$  denotes exports of manufacturing commodity  $p$  from country  $c$  and total exports of country  $c$ , respectively.  $pcgdp_c$  denotes real gross domestic product per capita of country  $c$ , derived from World Bank WDI Database. The weight,  $(X_{cp} / X_c) / \sum_c (X_{cp} / X_c)$  denotes the revealed export advantage index of manufacturing commodity  $p$  from country  $c$ .

The second stage is to evaluate the export sophistication at the national and sectoral levels. This paper draws on the practice of Li, et al. (2015) and divides 203 manufacturing commodities into different sector shares based on SITC, Rev. 3.

Specifically, the data from the agricultural and sideline food processing sector and the food manufacturing sector are integrated into the food processing and manufacturing sector, the data from the general equipment manufacturing sector and the special equipment manufacturing sector are integrated into the machinery manufacturing sector, and handicraft and other manufacturing sectors are integrated. The data of the industry sector and the waste of resources and material recycling-processing sector due to unclear classification are eliminated, and the number of 26 manufacturing industries is finally determined (see *Appendix 1* for details). The sector-level export sophistication formula is as follows:

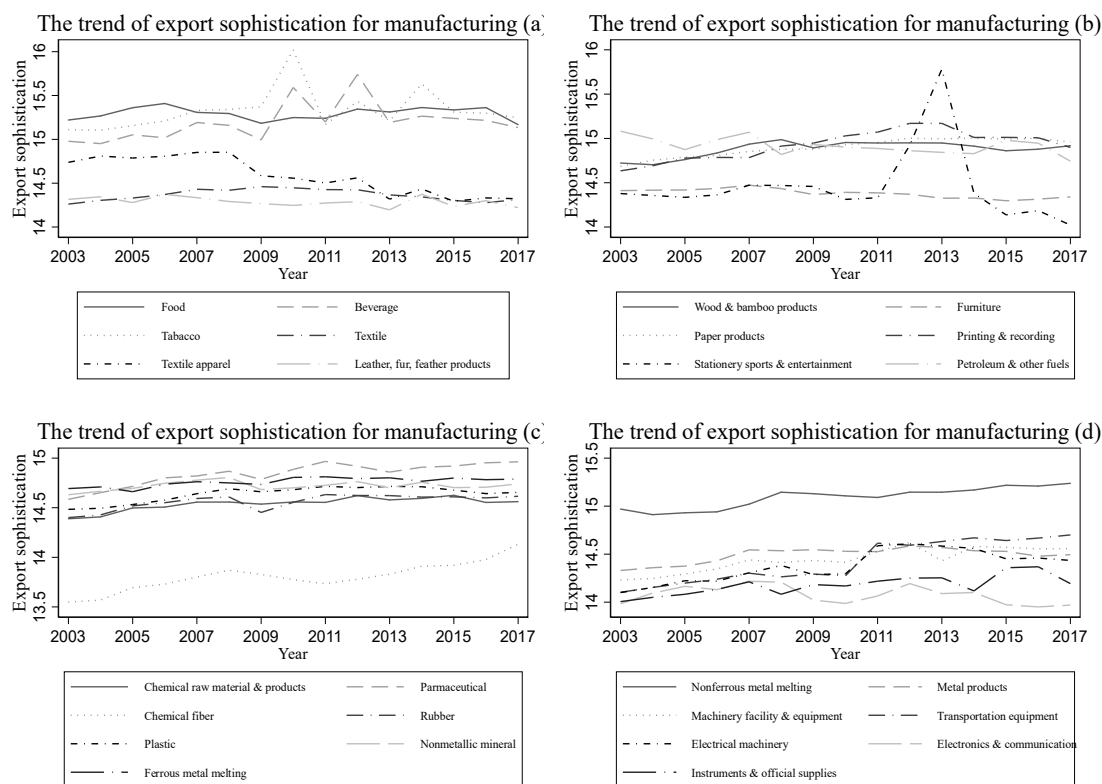
$$TSI_{ci} = \sum_{p=1}^m (X_{cip} / X_{ci}) PRODY_p \quad (2)$$

Where  $TSI_{ci}$  denotes the export sophistication at sectoral-level.  $X_{cip} / X_{ci}$  denotes the ratio of exports of manufacturing commodity  $p$  in sector  $i$  from country  $c$  to exports of sector  $i$  from country  $c$ .  $X_{cip}$  and  $X_{ci}$  denotes the exports of manufacturing commodity  $p$  in sector  $i$  from country  $c$  and exports of sector  $i$  from country  $c$ , respectively.  $m$  denotes the number of sectoral types.

*Fig. 2* shows the export sophistication of 26 Russia and Central and Eastern European countries as measured by Hausmann & Hidalgo (2010). The study found that the changing change of manufacturing export sophistication in Russia and 16 Central and Eastern European countries has the following characteristics. First, for resource-intensive and labor-intensive industries, such as textiles, textiles and clothing, leather, fur, feather products and other industries, the export sophistication continues to decline, while the export sophistication of beverages, tobacco and other industries fluctuates during the sample period. Second, the capital and technology-intensive industries, such as the chemical raw materials and chemical products sector, the pharmaceutical sector, the chemical fiber sector, the machinery sector, the transportation facility sector, the electrical machinery and equipment sector, the instrument and official supplies sector, have gradually increased during the sample period. These industries in Russia and Central and Eastern European countries are showing a positive economic growth change. Third, for resource-based traditional heavy industries, such as petroleum and other fuels, plastics, non-ferrous metal smelting and rolling, ferrous metal smelting and rolling, and non-metallic minerals, the export sophistication of these industries has changed, indicating that the economic conditions of these industries in Russia and Central and Eastern European countries are relatively good. Fourth, for other industries such as the stationary sports and entertainment industry and the electronic



communication equipment industry, the export sophistication has fallen sharply. The stationery sports and entertainment industry approached its highest point in 2013 and experienced a sharp decline (the largest decline among 26 manufacturing industries), the growth change of these industries is not optimistic.



**Fig. 2 The change of export sophistication of 26 manufacturing industries**

## 5. Econometrical framework

### 5.1 The econometric model

This paper takes the practice of Cernat (2001) and Huang, et al. (2017) as the reference to investigate the impact of trade facilitation on the export sophistication of Russia and Central-Eastern Europe countries based on "multiple states" pattern<sup>1</sup>. The benchmark econometrical model is developed as follow:

$$TSI_{cit} = \alpha_0 + \beta_1 LIB_{ct} RD_{ct} + \beta_2 RD_{ct} + \varphi X_{ct} + \gamma_i + \lambda_c + \varepsilon_{cit} \quad (3)$$

The pass-through, or transmission effect models are introduced as follow:

$$RD_{ct} = \alpha_0 + \beta_1 LIB_{ct} PASST_{cit} + \beta_2 PASST_{cit} + \varphi X_{ct} + \gamma_i + \lambda_c + \varepsilon_{cit} \quad (4)$$

$$TSI_{cit} = \alpha_0 + \beta_1 RD_{ct} + \varphi X_{ct} + \gamma_i + \lambda_c + \varepsilon_{cit} \quad (5)$$

Where the subscript  $c$  denotes the country,  $i$  denotes the manufacturing product,  $t$  denotes the year. The dependent variable  $TSI_{cit}$  denotes the natural log value of

<sup>1</sup> The so-called "multiple states" pattern, refers to the investigation of the impact of trade liberalization on export sophistication from the perspective of multiple sample countries by including the entire data of multiple samples, that differs from "single state" pattern, which from the single perspective.

export sophistication at commodity level,  $RD_{ct}$  denotes the R&D innovation,  $LIB_{ct}RD_{ct}$  represents the interaction of trade facilitation and R&D innovation, the key variable denotes R&D innovation that triggered by trade facilitation, depicting the truth of trade facilitation for propelling export facilitation through triggering R&D innovation.  $\gamma_i$ ,  $\lambda_c$  and  $\varepsilon_{cit}$  denote the fixed effect at product level, fixed effect at country level and error term, respectively.  $PASST_{cit}$ , the pass-through variables, is composed of imported intermediates  $INTERIMP_{cit}$  and foreign direct investment  $FDI_{ct}$ .

$X_{ct}$  denotes the control variables set, including: the economic development level,  $PGDP_{ct}$ . Some studies suggest that the economic development of a country correlates with its export capability, so the economic development level should be considered. It is measured by gross domestic product per capita and log-transformed, adjusted by purchasing power price in 2011 as the base price. The urbanization  $UR_{ct}$ . For countries with higher urbanization, the modern industrial systems are more comprehensive, thereby having the impact on the export competitiveness. The variable is measured by the ratio of urban population to the total population. The size of manufacturing production,  $IWA_{ct}$ . Many studies have shown that, the size of manufacturing production, as one kind of production capability, is able to promote the increase in the export flows and export performance. The variable is measured by the industrial value added that is log-transformed. The economic prosperity  $CDE_{ct}$ . The economic activities like the consumption, production, energy generation and transportation have the impact on the exports, and there is a positive correlation between prosperous economy and carbon dioxide emission, so the variable is measured by the kilotons of carbon dioxide emission that is log-transformed. The net inflows of foreign direct investment  $FDI_{ct}$ . In the field of international business, the foreign direct investment abroad, especially which entrenched advanced tech from developed economies, is deemed to be beneficial to promote the export sophistication of manufacturing industries domestically.

Introduce expanded variables to further examine the impact of trade facilitation on export sophistication, including the square terms of trade dependence, trade facilitation and R&D innovation. For continuous trade dependence, the numerator is trade flows, and the denominator is GDP. For the degree of separation from trade dependence, the ternary variable (0-3) is transformed based on the three quantiles of 25%, 50% and 75%. The expansion variables mentioned above have an expanded interaction with trade facilitation and R&D innovation. Introduce the square term of trade facilitation and

R&D innovation into a continuous expansion model.

## 5.2 Data and descriptive statistics

The exports concerning country category derived from the United Nations Comtrade database. All the secondary variables and control variables of the comprehensive trade facilitation index, per capita GDP, urban population, total population, industrial added value, carbon dioxide emissions, and net foreign direct investment inflows are derived from the World Development Index database of the World Bank. The data used in the pass-through section, that is, the intermediate products imported from the outside world and developed economies, are derived from the United Nations Comtrade database. Take endogeneity into consideration, instrumental variables are average tariff rate and the number of researchers that derived from the WITS database and the World Development Index database, respectively. The descriptive statistical results of the above variables are shown in *Table 2*.

**Table 2 The descriptive statistics**

Variable	Observations	Mean	Median	Min	Max
Dependent variable					
<i>TSI</i>	46000	14.66	14.56	13.55	16.02
<i>TSI_D</i>	46000	0.50	1	0	1
Independent variable					
<i>LIB·RD</i>	37000	0.96	0.91	0	2.61
<i>RD</i>	37000	0.57	0.56	0.02	1.28
Control variable					
<i>PGDP</i>	46000	9.21	9.36	7.95	10.15
<i>UR</i>	46000	0.48	0.48	0.36	0.56
<i>IVA</i>	46000	22.77	22.70	19.02	26.14
<i>CDE</i>	36000	10.41	10.03	7.51	14.42
<i>FDI</i>	44000	21.48	21.33	16.70	25.04
Pass-through variables					
<i>INTERATE</i>	45932	0.850	0.920	0.0100	1
<i>INTEFDRATE</i>	45932	0.850	0.920	0	1
<i>INTER</i>	45932	20.51	20.61	12.07	24.82
<i>INTERFD</i>	45932	19.53	19.70	5.180	24.12
<i>FDIGDP</i>	45932	0.0600	0.0400	0	0.540

Data source: derived from World Development Indicator Database and author's calculation.

## 6. Empirical results and analysis

In the section, the benchmark analysis, group analysis, robustness analysis and extended analysis are presented sequentially.

### 6.1 Benchmark analysis

The benchmark empirical results of the impact of trade facilitation on export

sophistication are shown in the *Table 3*. Column (1) includes only the variables of interest, the interaction between trade facilitation and R&D innovation, and innovation itself. Column (2) includes key variables and control variables.

**Table 3 The benchmark result of impact of trade facilitation on export sophistication**

Variable	(1)	(2)	(3)	(5)	(4)	(6)
<i>LIB·RD</i>	0.108*** (0.00)	0.039*** (0.00)	0.141*** (0.00)	0.056*** (0.00)	0.039*** (0.00)	0.024*** (0.00)
<i>RD</i>		0.040*** (0.01)			-0.060*** (0.01)	0.074*** (0.01)
<i>PGDP</i>		0.281*** (0.01)			0.269*** (0.01)	0.173*** (0.03)
<i>UR</i>		2.314*** (0.25)			1.433*** (0.24)	2.888*** (0.47)
<i>IVA</i>		0.031*** (0.01)			0.082*** (0.01)	0.148*** (0.02)
<i>CDE</i>		-0.063*** (0.01)			-0.086*** (0.01)	-0.039*** (0.01)
<i>FDI</i>		0.009*** (0.00)			0.013*** (0.00)	0.001 (0.00)
<i>Constant</i>	15.296*** (0.00)	11.781*** (0.16)	15.339*** (0.00)	15.175*** (0.00)	11.393*** (0.11)	0.000 (0.00)
<i>Fixed Effect</i>	Yes	Yes	Yes	Yes	Yes	Yes
<i>χ<sup>2</sup> Stats.</i>			281.40***		6.72**	
<i>P Value</i>				0.00	0.01	
<i>R<sup>2</sup></i>	0.199	0.310	0.390	0.0420	0.625	0.112
<i>Observation</i>	36910	32590	17779	19131	17580	15010

Note: The cluster robust standard deviation is given in parentheses, including fixed effects at the country and industry levels.  $\chi^2$  test is used to examine the difference in coefficients between sub-samples.

\*\*\* 1% significance level.

\*\* 5% significance level.

It is not difficult to find from column (1)-(2) that the coefficients of the key variables are all positive and significant at 1% level. Interactive results show that with the advancement of trade facilitation, 1% of R&D investment has led to an increase of about 0.108% in export sophistication. The positive impact of trade facilitation on export sophistication through R&D innovation in Russia and Central and Eastern European countries shows that the improvement of trade facilitation has promoted R&D and innovation, thereby improving the quality of commodities and enhancing the export competitiveness of the manufacturing industry. The coefficient of R&D innovation is 0.04, indicating that in the production of various commodities, there are spontaneous technological innovation activities that improve product quality, which is different from technological innovation triggered by external policies such as trade

facilitation. In addition, in terms of control variables, economic development, urbanization, manufacturing production scale, and foreign investment have a significant role in promoting export sophistication, and the impact of economic prosperity is negative, which may be related to the relatively wide range of economic growth patterns in developing countries.

Furthermore, this paper divides the sample period into two parts, 2003-2009 and 2010-2017, to examine the changes in the correlation between trade facilitation and export sophistication before and after the financial crisis. The empirical results between the two periods of the financial crisis are shown in columns (3)-(6). Comparing column (3)-(4) with column (5)-(6) shows the stability of the positive interaction effect. After 2009,  $\chi^2$  statistic for the difference in test coefficients within the sub-samples was all significant at 1% level, indicating that due to weak global demand, the interaction effect was relatively weakened. In addition, R&D innovation is significantly negatively correlated with export sophistication, which highlights the low efficiency of technology conversion and application. The positive coefficient of transfer shows that R&D innovation is more important to export performance.

## 6.2 Pass-through analysis

As mentioned above, the impact of trade facilitation on the quality and performance of export sophistication is indirect, which is different from the numerical performance of export inflows or outflows. Therefore, it is undeniable that there is a transmission path for the impact of trade facilitation on export sophistication. Judging from the existing literature, there are two potential transmission paths: intermediate products and foreign direct investment. In this section, this paper will make a follow-up analysis to examine the existence of these specific paths.

R&D innovation is an intermediate variable connecting trade liberalization and export sophistication. Methodologically, the panel two-step ordinary least regression is applicable and reliable to illustrate the conduction effect of correlation. In the first stage, the mediation variable R&D is used as the dependent variable to regress on imported intermediate products and foreign direct investment, including the main effect and the interaction effect with trade facilitation; in the second stage, the export sophistication is used as the dependent to regress on R&D innovation. Therefore, trade facilitation, R&D innovation and export sophistication are included in a comprehensive framework. *Table 4* shows the empirical results. For robustness, the instrumental variable  $INTERIMP_{ct}$  is determined by the share of imported intermediate goods abroad and the



Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and industry level are included. The validity test for instrument variables are conducted.

\*\*\* 1% significance level.

\*\* 5% significance level.

\* 10% significance level.

The Wald test result for the validity of the instrument variables is almost at the level of 1%. The results of the pass-through effect are given in the first stage regression. The interaction of imported intermediate products, foreign direct investment and trade facilitation reflects its positive advancement in R&D and innovation. But the main effect of each transmission path is different. For the pass-through path of imported intermediate products, the coefficients of flow form and share form are positive and negative respectively. The possible explanation is that with the increase in the scale of imported intermediate products, R&D and innovation promoted by the "technological spillover" effect came into being, and the increase in the share of intermediate products, especially the increase in the share of intermediate products from developed economies, also The "import dependence" effect or "capturing" effect that may cause damage to domestic R&D innovation, the positive interaction effect just reveals that trade facilitation improves the efficiency of technology absorption, which translates into R&D improvement. Regarding the transmission path of foreign direct investment, no matter whether it is net inflow or utilization rate, it seems that there is no "learning by doing" effect of increasing export sophistication without improving trade facilitation.

What is worthy of recognition is that in the second stage of regression, R&D innovation is positively correlated with export sophistication, because the former is the most fundamental factor driving the overall improvement of the latter.

### 6.3 Subsample analysis

The aforementioned benchmark analysis fails to show the heterogeneity of the impact of trade facilitation on export sophistication based on different standards. In order to further examine the effect of heterogeneity, this paper divides the country sub-sample and the industry subsample.

#### 6.2.1 National subsample analysis

First of all, this paper divides the sample countries into Eastern European subsample and Central European subsample including Russia from a geographical perspective. Moreover, from the perspective of EU member states, the sample is divided into two parts (see *Appendix 2*). The empirical results are shown in the *Table 5*.

**Table 5 The subsample analysis for geographic distribution and membership of EU**

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<i>LIB·RD</i>	0.108***	0.110***	0.023***	0.050***	0.101***	0.109***	0.035***	0.038***

	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
<i>RD</i>			0.127***	-			-	0.089***
				0.035***			0.107***	
			(0.02)	(0.01)			(0.02)	(0.01)
<i>PGDP</i>			0.092*	0.299***			0.264***	0.257***
			(0.05)	(0.02)			(0.04)	(0.02)
<i>UR</i>			3.744***	1.632***			1.584***	2.423***
			(0.39)	(0.39)			(0.51)	(0.32)
<i>IVA</i>			0.167***	0.028***			0.088***	0.034**
			(0.03)	(0.01)			(0.01)	(0.01)
<i>CDE</i>			-0.014	-			-	-
				0.043***			0.076***	0.065***
			(0.02)	(0.01)			(0.02)	(0.01)
<i>FDI</i>			0.006***	0.010***			0.011***	0.009***
			(0.00)	(0.00)			(0.00)	(0.00)
<i>Constant</i>	0.000	15.295**	8.437***	11.793**	15.296**	15.119**	11.154**	0.000
		*	*	*	*	*	*	
	(0.00)	(0.00)	(0.51)	(0.17)	(0.00)	(0.00)	(0.18)	(0.00)
<i>F.E.</i>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
$\chi^2$ Stats.		8.04***		147.77***		30.46***		382.81***
<i>P Value</i>		0.00		0.00		0.00		0.00
$R^2$	0.326	0.133	0.426	0.257	0.124	0.229	0.265	0.334
<i>Observation</i>	12111	22404	10323	20054	10157	26753	8997	23593

Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and industry are included.  $\chi^2$  tests for investigating the difference in coefficients among subsamples are conducted.

\*\*\* 1% significance level.

\*\* 5% significance level.

\* 10% significance level.

The regional subsample results are listed in columns (1)-(4), representing Eastern Europe, (1)-(3) and Central Europe, and (2)-(4), respectively. Both the interaction coefficient and the innovation coefficient have a positive effect at 1% significance level, indicating that both trade facilitation and innovation have significantly increased the sophistication of exports, which has an enlightening effect on export competitiveness. From a horizontal comparison point of view, the interactive effect of China and Europe is more obvious, which may be due to the geographical location of Western Europe, which is close to developed economies, and is equipped with more advanced manufacturing equipment and facilities.

The results are shown in columns (3) and (4), which include non-EU member states and EU member states. The positive interaction effect of trade facilitation and R&D innovation of EU member states exceeds that of others. It seems to be explained that due to the low efficiency and harsh environment of non-EU member states, the effect



of trade facilitation is not enough to improve the region's export competitiveness.

For a country that can rely on a stable economic environment, the EU member states can benefit from the support of other member states in terms of technology and finance, and the significant results of R&D and innovation vary among groups.

### 6.2.2 Analysis of industry sub-samples

Based on different manufacturing standards, we can further examine the heterogeneity of the impact of trade facilitation on export sophistication. In order to further examine the correlation between trade facilitation and export sophistication in different types of industries, this paper draws on the practice of Li, et al. (2015), based on light and heavy sub-samples, homogeneous heterogeneous sub-samples, and technical content sub-samples.

#### 6.2.2.1 Sub-sample analysis of light and heavy industries

On the basis of the division of severity, the 26 manufacturing industries in Russia and Central and Eastern European countries are divided into two parts: light and heavy manufacturing (see *Appendix 3*). Light industry refers to the industry that provides survival materials and hand tools. The corresponding heavy industry is defined as the provision of technical equipment, electricity, raw materials and other production materials for various industries in the national economy. The so-called light and heavy sub-sample are one of the widely used industrial classifications, which can be traced back to Eastern European countries such as the former Soviet Union. Although the definition has characteristics of planned economy, it still has a certain degree of reference. The empirical results are shown in *Table 6*.

**Table 6** The subsample analysis for light-heavy industry

Variable	(1)	(2)	(3)	(4)
<i>LIB·RD</i>	0.137*** (0.00)	0.052*** (0.00)	0.036*** (0.00)	0.042*** (0.00)
<i>RD</i>			0.084*** (0.01)	-0.039** (0.02)
<i>PGDP</i>			0.436*** (0.01)	0.015 (0.03)
<i>UR</i>			3.126*** (0.24)	0.819* (0.46)
<i>IVA</i>			0.004 (0.01)	0.077*** (0.02)
<i>CDE</i>			-0.108*** (0.01)	0.014 (0.02)
<i>FDI</i>			0.004*** (0.00)	0.017*** (0.00)

<i>Constant</i>	14.534*** (0.00)	15.327*** (0.01)	10.814*** (0.14)	12.854*** (0.32)
<i>Fixed Effect</i>	Yes	Yes	Yes	Yes
<i>χ<sup>2</sup> Stats.</i>		847.73		792.01
<i>P Value</i>		0.00		0.00
<i>R<sup>2</sup></i>	0.345	0.0419	0.555	0.0842
<i>Observation</i>	23990	12920	21173	11417

Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and industry are included.  $\chi^2$  tests for investigating the difference in coefficients among subsamples are conducted.

\*\*\* 1% significance level.

\*\* 5% significance level.

\* 10% significance level.

As shown in *Table 6*, columns (1)-(3) and (2)-(4) are the results of the heavy industry and light industry sub-samples, respectively. The coefficients of key variables are relatively stable, and the interaction of trade facilitation and R&D innovation significantly promotes the export sophistication of the two sub-samples. It is not difficult to understand that heavy industries such as the petroleum and other fuel sectors, chemical materials and products sectors, rubber and plastics sectors, ferrous and non-ferrous metal smelting sectors, and machinery sectors are highly dependent on production technology and are extremely vulnerable to trade facilitation. Trade facilitation can effectively stimulate innovation enthusiasm and technological transformation efficiency by obtaining foreign direct investment and advanced technology from developed economies, or obtaining imported intermediate products, improving original production skills, and enhancing the performance of export commodities. For the light industry sub-sample, R&D innovation is negatively correlated with export sophistication. The understandable results show that as traditional industries in light industry, such as food, tobacco and liquor, textiles, wood, stationery, sports and entertainment, most of them belong to Resource and labor-intensive industries are less susceptible to the impact of R&D innovation, and rely more on access to factors such as labor and natural resources.

### 6.2.3 Sub-sample analysis of differentiated industries

This paper draws on the practice of Rauch (1999), aggregates different types of commodities based on SITC, Rev. 3 by 3-digit, and divides the manufacturing industries in Russia and Central and Eastern European countries into homogeneous industries and differentiated industries according to the differentiation criteria (see *Appendix 4*). The possession of a preference price distinguishes homogeneity from difference. Taking the petroleum sector as an example, sales prices can be quoted without mentioning the

name of the manufacturer. These "reference prices" have been found by industry actors to be of sufficient help and are worth listing on trade publications, so they are called homogeneous industries. For industries such as shoes and machinery, there is no reference price. Any price observed in another location must be adjusted according to the multi-dimensional differences in characteristics, which depends on the variety of products available at that location and the distribution of consumer preferences for the variety of the location, so it is called a differentiated industry. The results are shown in *Table 7*.

**Table 7 The subsample analysis for differentiated industry**

Variable	(1)	(2)	(3)	(4)
<i>LIB·RD</i>	0.056*** (0.00)	0.142*** (0.00)	0.042*** (0.00)	0.035*** (0.00)
<i>RD</i>			-0.033** (0.02)	0.092*** (0.01)
<i>PGDP</i>			0.033 (0.02)	0.455*** (0.01)
<i>UR</i>			0.697* (0.40)	3.422*** (0.25)
<i>IVA</i>			0.068*** (0.01)	0.005 (0.01)
<i>CDE</i>			0.012 (0.02)	-0.117*** (0.01)
<i>FDI</i>			0.014*** (0.00)	0.005*** (0.00)
<i>Constant</i>	15.330*** (0.01)	13.745*** (0.00)	13.013*** (0.27)	9.414*** (0.16)
<i>Fixed effect</i>	Yes	Yes	Yes	Yes
$\chi^2$ Stats.	2783.69		2412.97	
<i>P Value</i>	0.00		0.00	
$R^2$	0.0677	0.309	0.117	0.502
<i>Observation</i>	14893	22017	13149	19441

Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and industry are included.  $\chi^2$  tests for investigating the difference in coefficients among subsamples are conducted.

\*\*\* 1% significance level.

\*\* 5% significance level.

\* 10% significance level.

Columns (1)-(3) and (2)-(4) show empirical results of sub-samples of homogeneous industries and differentiated industries. The results show that for food, textile, petroleum, and non-metallic mineral equivalent industries, due to the internal homogeneity of the industry is high, and only relying on strengthening R&D innovation cannot effectively promote the improvement of export competitiveness and the

expansion of international market share. Under the conditions of trade facilitation, the positive impact of R&D innovation on export competitiveness is significant at 1% level. For differentiated industries, the key variables are significantly positive at 1% level, and the coefficients are relatively close. This paper takes chemical, pharmaceutical, ferrous and non-ferrous metals, machinery, electronics, and communication equipment industries as typical representative industries in differentiated industries. Due to the high degree of differentiation within the industry, it determines the importance of R&D and innovation in industrial development. In addition, the potential "technological spillover" effect of imported high-quality intermediate products brought about by trade facilitation and foreign direct investment will surely promote the improvement of production and efficiency.

#### 6.2.4 Subsample analysis of technology types

Among many methods to define the type of manufacturing technology, the OECD estimate is the most representative. In 1986, the OECD formally formulated the definition of high-tech industry based on the ratio of R&D expenditure to industrial production and the intensity of R&D expenditure as the defining criteria, and subsequently adjusted the estimates since 1994. In 2003, OECD divided the manufacturing industry into four categories: high technology, medium and high technology, medium and low technology, and low technology according to ISIC and Rev. 3. This paper draws on the practice of OECD (2003) and considers the problem of sample balance. It integrates medium and high technology and low and medium technology industries into medium and high technology industries, and is divided into three parts accordingly (see *Appendix 5*). The empirical results are shown in *Table 8*.

**Table 8 The subsample analysis for tech-type industry**

Variable	(1)	(2)	(3)	(4)	(5)	(6)
<i>LIB·RD</i>	0.044*** (0.00)	0.090*** (0.00)	0.162*** (0.00)	0.041*** (0.00)	0.018*** (0.00)	0.045*** (0.00)
<i>RD</i>				-0.043** (0.02)	0.061*** (0.01)	0.096*** (0.01)
<i>PGDP</i>				-0.016 (0.03)	0.349*** (0.02)	0.485*** (0.01)
<i>UR</i>				0.661 (0.47)	1.816*** (0.36)	3.833*** (0.26)
<i>IVA</i>				0.078*** (0.02)	-0.006 (0.01)	0.011 (0.01)
<i>CDE</i>				0.021 (0.02)	-0.044*** (0.02)	-0.140*** (0.01)
<i>FDI</i>				0.017***	0.005***	0.004***

				(0.00)	(0.00)	(0.00)
<i>Constant</i>	15.329***	13.784***	14.786***	13.089***	0.000	10.143***
	(0.01)	(0.00)	(0.00)	(0.33)	(0.00)	(0.15)
<i>Fixed Effect</i>	Yes	Yes	Yes	Yes	Yes	Yes
$\chi^2$ Stats.		1795.96***			1623.48***	
<i>P Value</i>		0.00			0.00	
$R^2$	0.0305	0.271	0.392	0.0690	0.464	0.620
<i>Observation</i>	12166	8264	16480	10752	7294	14544

Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and industry are included.  $\chi^2$  tests for investigating the difference in coefficients among subsamples are conducted.

\*\*\* 1% significance level.

\*\* 5% significance level.

Columns (1)-(4), (2)-(5) and (3)-(6) show the empirical results of low-tech, medium-tech and high-tech industries, respectively. There are differences in the positive interaction coefficients of the subsamples of various technology types, which are manifested in the increase in the marginal impact on the sophistication of export technology with the improvement of technology level, and the interaction effects of medium technologies such as oil, rubber, and plastics are added to R&D innovation and control After variables is not stable, the coefficient is 0.09, and it drops to 0.018. The impact on low-tech R&D innovation is negative, indicating that for low-tech industries, labor-intensive and resource-intensive industries such as food, textile, wood and furniture, papermaking and printing, the technological content is low, and it relies more on the cost advantages of labor and resource input to enhance its competitiveness. For high-tech industries such as medicine, machinery, electronic communication, instrumentation, etc., whether it is the impact of trade facilitation or the impact of R&D and innovation, they have significantly promoted the sophistication of the export of medium and high-tech industries, showing their impact on domestic trade and technology. Sensitivity to level obstacles.

### 6.3 Robustness analysis

In the robustness analysis in this section, in order to further verify the impact of trade facilitation and R&D innovation on export sophistication. Considering the endogenous problem, this paper adopts the two-stage least squares model (2SLS) to estimate the correlation. In addition, to test the robustness of the benchmark model, a restricted dependent variable model is introduced.

#### 6.3.1 Endogenous problems

Endogeneity is a problem that cannot be ignored in econometrics. For the independent variable of this paper, trade facilitation, as an indicator that

comprehensively measures port efficiency, customs environment, regulatory environment, and e-commerce, is a centralized policy that reduces trade barriers and improves the efficiency of capital flow, a kind of systematic openness that does not have the matter of endogeneity. But it is likely that the variable R&D innovation is endogenous. On the one hand, R&D innovation is positively correlated with manufacturing export competitiveness. Conversely, the industry with stronger export competitiveness determines the higher the intensity of R&D investment, that is, mutual causality. On the other hand, R&D innovation is largely susceptible to the influence of specific manufacturing sectors that may be related to other unobservable factors in the random error term not included in the model, that is, the problem of missing variables.

Considering the robustness and convenience, without loss of generality, this paper uses the 2SLS method to introduce three types of instrumental variables to solve the endogenous problem: First, considering the conventions in the relevant literature, the industry-level endogenous variables are averaged. The first lag or the second lag between the endogenous variables and the endogenous variables are used as effective instrumental variables (Lu, 2018; Yu, 2014), because there is a strong correlation between them, and there is no significant correlation with the error term. Secondly, this paper introduces the product of the average tariff rate and the number of researchers as the interaction item between trade facilitation and R&D innovation. As a kind of exogenous trade policy, the tariff rate is usually lower in countries that implement trade facilitation. From a point of view, the number of researchers is related to R&D innovation, not other variables of interest, so both meet the criteria as tools. The empirical results are shown in *Table 9*.

**Table 9 The endogeneity analysis**

Variable	(1) Lag	(2) Lag	(3) Mean	(4) Mean	(5) TR	(6) TR
<i>LIB·RD</i>	0.099*** (0.01)	0.035** (0.02)	0.071*** (0.00)	0.045*** (0.00)	0.137*** (0.01)	0.122*** (0.01)
<i>RD</i>		0.086*** (0.03)		0.366*** (0.02)		0.186*** (0.03)
<i>PGDP</i>	0.141*** (0.01)	0.223*** (0.02)	0.227*** (0.01)	0.303*** (0.01)	0.122*** (0.02)	0.150*** (0.02)
<i>UR</i>	0.910*** (0.19)	1.933*** (0.36)	1.886*** (0.12)	1.683*** (0.13)	0.871*** (0.19)	0.103 (0.19)
<i>IVA</i>	0.017** (0.01)	0.014 (0.01)	0.029*** (0.00)	-0.093*** (0.01)	-0.004 (0.01)	-0.085*** (0.01)
<i>CDE</i>	0.016* (0.01)	-0.013 (0.01)	-0.039*** (0.01)	0.004 (0.01)	0.024** (0.01)	0.096*** (0.01)

<i>FDI</i>	0.008*** (0.00)	0.007*** (0.00)	0.008*** (0.00)	0.019*** (0.00)	0.009*** (0.00)	0.011*** (0.00)
<i>Constant</i>	13.126*** (0.20)	11.900*** (0.29)	12.255*** (0.10)	13.564*** (0.13)	13.645*** (0.21)	14.685*** (0.19)
<i>Fixed Effect</i>	Yes	Yes	Yes	Yes	Yes	Yes
<i>Wald Stats.</i>	195.69	151.07	1296.48	1490.00	226.36	752.49
<i>Instrument P</i>	0.00	0.00	0.00	0.00	0.00	0.00
<i>R<sup>2</sup></i>	0.200	0.130	0.302	0.260	0.255	0.161
<i>Observation</i>	27338	22602	32590	32590	32590	27826

Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and industry are included. Wald tests for investigating the difference in coefficients among subsamples are conducted.

The fixed effect is considered in the two stage least square model.

\*\*\* 1% significance level.

\*\* 5% significance level.

\* 10% significance level.

The model uses the first lag of endogenous variables, the average value of endogenous variables at the industry level, the average tariff rate and the number of researchers in columns (1)-(2), (3)-(4), and (5)-(6). It indicates that the coefficients of independent variables are stable, indicating that trade facilitation and R&D innovation are positively correlated with manufacturing export sophistication, which is consistent with the results of the benchmark model.

### 6.3.2 Robustness of model specification analysis

This paper uses the panel Tobit model and the panel Logit model to verify the robustness of the model specification. First of all, the logarithm range of the minimum export sophistication is 13 to 17, so the censoring correlation var is suitable for the regression panel Tobit model. Further, according to the median value of the dependent variable, the continuous variable is converted into a binary variable, and the value greater than the median value is set to 1, otherwise it is zero, and then the panel Logit model is used for regression. The empirical results are shown in *Table 10*.

**Table 10 The robustness of model specification analysis**

Variable	(1)	(2)	(3)	(4)
<i>LIB·RD</i>	0.108*** (0.00)	0.039*** (0.00)	3.351*** (0.06)	1.245*** (0.09)
<i>RD</i>		0.040*** (0.01)		4.445*** (0.37)
<i>PGDP</i>		0.281*** (0.01)		11.082*** (0.56)
<i>UR</i>		2.314*** (0.12)		140.010*** (8.49)
<i>IVA</i>		0.031*** (0.01)		-0.534 (0.35)

<i>CDE</i>		-0.063***		-6.559***
		(0.01)		(0.33)
<i>FDI</i>		0.009***		-0.357***
		(0.00)		(0.04)
<i>Constant</i>	15.296***	11.781***	-3.352***	-77.494***
	(0.01)	(0.10)	(0.25)	(6.45)
<i>Fixed Effect</i>	Yes	Yes	Yes	Yes
<i>Observation</i>	36910	32590	17964	15886

Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and industry are included.

\*\*\* 1% significance level.

As shown in *Table 10*, columns (1)-(2) and (3)-(4) show the results of the panel Tobit model and the panel Logit model, respectively, using the Bootstrap method, and the number of iterations is 500. From the empirical results, no matter what detailed regression method is used, the positive interaction effect of trade facilitation and R&D innovation on export sophistication is significant at 1% level, which is consistent with the results of the aforementioned benchmark model. In addition, the influence of the included control variables on export sophistication reflects the robustness of the benchmark model specification.

## 6.4 The extensive analysis

### 6.4.1 Trade dependency

Trade dependency refers to the dependence of a particular economy on international trade, which reflects the degree of participation in global economic activities, and is evaluated as the ratio of a country's economy's trade flow to its gross domestic product. Under the adjustment of trade dependence, the impact of trade facilitation on manufacturing export sophistication may vary. For the measurement of trade dependence, from the perspective of sustainability, the ratio of trade flows to gross domestic product is used. From the point of view of ordinal numbers, the three percentiles of 25%, 50%, and 75% of continuous variables are converted into ordinal numbers 1-3 to generate interaction terms with variable trade facilitation and R&D innovation, and key variables are incorporated into the model. The empirical model is as follows:

$$TSI_{cit} = \alpha_0 + \beta_1 LIB_{ct} RD_{ct} TD_{ct} + \beta_2 RD_{ct} + \varphi X_{ct} + \gamma_i + \lambda_c + \varepsilon_{cit} \quad (6)$$

Where  $TD_{ct}$  denotes the continuous trade dependency,  $OTD_{ct}$  denotes the ordinal trade dependency. The empirical results are presented as columns (1)-(2) in *Table 11*.

### 6.4.2 Analysis of nonlinear effects



The aforementioned research on the impact of trade facilitation and R&D innovation on the sophistication of manufacturing exports is based on the basic assumption of linear effects, considering that trade facilitation and R&D innovation have potential nonlinear effects on the sophistication of manufacturing exports. In other words, with the advancement of trade facilitation and R&D innovation, their marginal effects on the sophistication of manufacturing exports are likely to show increasing characteristics or follow a decreasing law.

The interaction of the square term of trade facilitation, R&D innovation, and the square term of R&D innovation is a nonlinear effect on export sophistication. The measurement model is as follows:

$$TSI_{cit} = \alpha_0 + \beta_1 LIB\_S_{ct} RD_{ct} + \beta_2 RD_{ct} + \varphi X_{ct} + \gamma_i + \lambda_c + \varepsilon_{cit} \quad (7)$$

$$TSI_{cit} = \alpha_0 + \beta_1 LIB_{ct} RD\_S_{ct} + \beta_2 RD\_S_{ct} + \varphi X_{ct} + \gamma_i + \lambda_c + \varepsilon_{cit} \quad (8)$$

Where the variables  $LIB\_S_{ct} RD_{ct}$ ,  $LIB_{ct} RD\_S_{ct}$ , and  $RD\_S_{ct}$  denote the nonlinear effect of trade facilitation, the interaction of trade facilitation and R&D innovation squares, and the nonlinear effect of R&D innovation, respectively. The empirical results are presented as columns (3)-(4) in *Table 11*.

**Table 11 The trade dependency analysis**

Variable	(1)	(2)	(3)	(4)
<i>LIB·RD·TD</i>	0.045*** (0.00)	0.024*** (0.00)		
<i>LIB_S·RD</i>			0.017*** (0.00)	
<i>LIB·RD_S</i>				0.035*** (0.00)
<i>RD2</i>				0.012** (0.01)
<i>RD</i>	0.007 (0.01)	0.035*** (0.01)	0.066*** (0.01)	
<i>PGDP</i>	0.257*** (0.01)	0.294*** (0.01)	0.284*** (0.01)	0.306*** (0.01)
<i>UR</i>	2.268*** (0.25)	2.363*** (0.25)	2.306*** (0.25)	2.417*** (0.24)
<i>IVA</i>	0.027*** (0.01)	0.024*** (0.01)	0.030*** (0.01)	0.026*** (0.01)
<i>CDE</i>	-0.040*** (0.01)	-0.057*** (0.01)	-0.058*** (0.01)	-0.061*** (0.01)
<i>FDI</i>	0.007*** (0.00)	0.009*** (0.00)	0.010*** (0.00)	0.009*** (0.00)
<i>Constant</i>	11.920*** (0.17)	11.768*** (0.17)	11.737*** (0.16)	11.642*** (0.16)

<i>Fixed Effect</i>	Yes	Yes	Yes	Yes
$R^2$	0.320	0.306	0.309	0.311
<i>Observation</i>	30490	32590	32590	32590

Notes: the clustering robust standard deviation is presented in parentheses, fixed effects at country and commodity class are included.

\*\*\* 1% significance level.

\*\* 5% significance level.

It can be seen from *Table 11* that the interaction coefficients of trade facilitation, R&D innovation, and trade dependence are significantly positive at 1% level. The enlightenment from the economic perspective is that as a country's trade dependence increases, trade facilitation and R&D innovation have an enhanced role in promoting the export sophistication of the manufacturing industry. Trade dependence reflects the degree of a country's connection with the world, and its dependence on foreign trade. In countries with a relatively high degree, the promotion of trade facilitation and R&D innovation on the sophistication of manufacturing exports will be more stimulated by interaction effects. In terms of nonlinearity, the non-linear effects of trade facilitation and R&D are both positive at 1% significance level, indicating that the marginal effects of the two on export sophistication are getting stronger.

## 7. Main conclusions

This paper examines the impact of trade facilitation and R&D innovation on the export sophistication of Russia and Central and Eastern European countries from the perspective of the evolution of manufacturing export sophistication from 2003 to 2017.

The main research conclusions are as follows: the export sophistication of labor-intensive industries is on a downward change, the export sophistication of capital and technology-intensive industries is on the rise, and the export sophistication of traditional resource-based industries is on a steady rise. The positive effects of trade facilitation and R&D innovation on the sophistication of manufacturing exports vary based on different standards. In terms of time span, after the 2009 financial crisis, the impact of R&D innovation on export sophistication has increased. In terms of regional distribution, for transition economies located in Central Europe or belonging to the EU, the interactive effect of trade facilitation and R&D innovation on export sophistication is more significant than that of economies located in Eastern Europe or not belonging to the EU. From the perspective of industry classification, for the heavy-duty, differentiated, and high-tech manufacturing industry, the positive interaction effect of trade facilitation and R&D innovation on export sophistication is more obvious than that of light, homogenous, and low-tech manufacturing. In the extensive analysis, the

degree of trade dependence has a significant positive impact on trade facilitation and R&D innovation. In addition, trade facilitation and R&D innovation both have a marginal increasing nonlinear impact on the export sophistication of manufacturing.

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***Appendix 1 The aggregated commodity at 3- digit of 27 manufacturing industries***

Manufacturing industry	Manufacturing sector
Food	011, 012, 016, 017, 022, 023, 024, 025, 034, 035, 037, 042, 045, 046, 047, 048, 054, 056, 058, 059, 061, 062, 071, 073, 075, 081, 091, 098, 411, 421, 422, 431
Beverage	074, 111, 112
Tobacco	122
Textile	269, 651, 652, 653, 654, 655, 656, 657, 658, 659
Garment & Fibrous Products	841, 842, 843, 844, 845, 846, 848
Leather, Fur&Down	611, 612, 613, 831, 851
Wood, Bamboo & Palm	633, 634, 635
Furniture	821
Paper	251, 641, 635
Printing & Recording Media	892
Cultural Stationery & Entertainment	894, 895, 898
Petroleum	325, 334, 335
Chemical Raw Material & Product	232, 511, 512, 513, 514, 515, 516, 522, 523, 524, 525, 531, 532, 533, 551, 553, 554, 562, 571, 572, 573, 574, 575, 579, 591, 592, 593, 597, 598
Pharmaceutic	541, 542
Chemical Fiber	266, 267
Rubber	621, 625, 629
Plastic	581, 582, 583, 893
Non-Metallic Mineral	661, 662, 663, 664, 665, 666, 667
Ferrous Metal Melting and Rolling	671, 672, 673, 674, 675, 676, 677, 678, 679
Nonferrous Metal Melting and Rolling	681, 682, 683, 684, 685, 687, 689
Metallic Product	691, 692, 693, 694, 695, 696, 699, 811, 812
General Machinery Facility	711, 712, 713, 714, 716, 718, 731, 733, 735, 737, 741, 742, 743, 744, 745, 746, 747, 748, 749
Special Machinery Facility	721, 722, 723, 724, 725, 726, 727, 728, 774, 872, 881, 882, 883
Communication & Transportation Facility	781, 782, 783, 784, 785, 786, 791, 792, 793
Electrical Machinery and Equipment	771, 772, 773, 775, 776, 778, 813
Electronical and Communicative Equipment	752, 761, 762, 763, 764
Apparatus & Office Machinery	751, 759, 871, 873, 874, 884, 885

Based on Standard International Trade Classification, SITC, Rev. 3.

**Appendix 2 Country Division (by geography and EU membership)**

Eastern European Country	Central European Country
Russia	Bulgaria
Hungary	Croatia
Czech	Serbia
Slovakia	Latvia
Slovenia	Bosnia & Herzegovina
Poland	Estonia
	Lithuania
	Romania
	Albania
	Macedonia
	Montenegro
EU Country	Non-EU Country
Hungary	Russia
Czech	Serbia
Slovakia	Bosnia & Herzegovina
Slovenia	Albania
Poland	Macedonia
Bulgaria	Montenegro
Croatia	
Latvia	
Estonia	
Lithuania	
Romania	

**Appendix 3 Light-Heavy Industry Division**

Light Industry	Heavy Industry
Food	Petroleum
Beverage	Chemical Raw Material & Product
Tobacco	Rubber
Textile	Plastic
Garment & Fibrous Products	Non-Metallic Products
Leather, Fur&Down	Ferrous Metal Melting and Rolling
Wood, Bamboo & Palm	Nonferrous Metal Melting and Rolling
Furniture	Metallic Product
Paper	General Machinery Facility
Printing & Recording Media	Special Machinery Facility
Cultural Stationery & Entertainment	Communication & Transportation Facility
Pharmaceutic	Electrical Machinery and Equipment
Chemical Fiber	Electronical and Communicative Equipment
	Apparatus & Office Machinery

**Appendix 4 Differentiation of Industry Division**

Homogeneous Industry	Differentiated Industry
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Food	Leather, Fur&Down
Beverage	Cultural Stationery & Entertainment
Tobacco	Chemical Raw Material & Product
Textile	Pharmaceutic
Garment & Fibrous Products	Chemical Fiber
Wood, Bamboo & Palm	Rubber
Furniture	Ferrous Metal Melting and Rolling
Paper	Metallic Product
Printing & Recording Media	General Machinery Facility
Petroleum	Special Machinery Facility
Plastic	Communication & Transportation Facility
Non-Metallic Products	Electrical Machinery and Equipment
Nonferrous Metal Melting and Rolling	Electronical and Communicative Equipment
	Apparatus & Office Machinery

**Appendix 5 Technological Type of Industry Division**

Low-Tech Industry	Medium-Tech Industry	High-Tech Industry
Food	Petroleum	Chemical Raw Material &
Beverage	Chemical Raw Material &	Product
Tobacco	Product	Pharmaceutic
Textile	Non-Metallic Products	General Machinery Facility
Garment & Fibrous Products	Ferrous Metal Melting and	Special Machinery Facility
Leather, Fur&Down	Rolling	Communication &
Wood, Bamboo & Palm	Nonferrous Metal Melting and	Transportation Facility
Furniture	Rolling	Electrical Machinery and
Paper	Metallic Product	Equipment
Printing & Recording Media		Electronical and
Cultural Stationery &		Communicative Equipment
Entertainment		Apparatus & Office Machinery