Digital Economy Development, International Trade Efficiency and Trade Uncertainty

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From the perspective of international trade efficiency and trade uncertainty, this paper analyzes the impact of digital economy development (DED) in importing countries on China's exports. Theoretically, importing countries' DED can reduce the trade cost of China's exports, and then improve the export efficiency of China. On the other hand, the intensified market competition in importing countries resulting from DED and the changes in data transmission policies may also increase the uncertainty of China's export trade. This paper uses the networked readiness index (NRI) to measure the DED level of different countries, and the heterogeneous stochastic frontier gravity (HSFG) model to empirically analyze the data of China's exports to 115 countries and regions in the period of 2007−2015. The results show that the DED in importing countries can significantly reduce the loss of China's export efficiency and improve the efficiency of China's export trade, and this effect is more obvious for China's exports to low- and middle-income countries. However, importing countries' DED may also increase the uncertainty of China's export trade. The development of global digital economy brings new opportunities to international trade and new challenges to China's export. This paper provides a basis for China to strengthen its own DED, deepen international exchanges and cooperation, guide enterprises' transformation and upgrading, and improve their competitiveness and anti-risk capability.

Keywords: digital economy, international trade, trade efficiency, heterogeneous stochastic frontier gravity model

1. Introduction

As General Secretary Xi Jinping pointed out at the 26th APEC Economic Leaders' Meeting held in November 2018, "digital economy represents the development of the future for both the Asia-Pacific and the world at large". In the era of digital economy, information and communications technology (ICT) has changed the operation mode of society and enterprises, with data information storage and processing capacity reaching an unprecedented high level. A series of market changes caused by this have made all countries in the world begin to realize that DED will bring new opportunities and

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challenges. In the wave of "the fourth industrial revolution", how to improve national competitiveness through DED and data security protection is a key topic that has drawn more and more attention in the international community today.

The development and application of ICT also have a profound impact on the international trade market. From the perspective of trade subjects, the application of Internet and digital technology has reduced the access cost of international trade, and enabled more micro, small and medium-sized enterprises to participate in and benefit from international trade. From the perspective of trade objects, the application of ICT has reduced trade costs, expanded the scope of market and tradable products, and many of the products and services that were previously difficult to trade or that were not profitable under traditional trade conditions, such as folk handicrafts, cross-border financial and medical services, etc., have also begun to appear in the international trade market. In addition, the flattening of trade channels enables enterprises to quickly get the information about market changes, and the application of digital technology also increases the efficiency of product upgrading and innovation.

International trade efficiency refers to the distance between the actual trade volume and the optimal trade volume, while trade uncertainty is used to describe trade fluctuations caused by changes in trade costs. On the basis of theoretical mechanism analysis, this paper uses the HSFG model to explore the influence of importing countries' DED on China's export trade efficiency and trade uncertainty. On the one hand, the paper, from the perspective of trade efficiency, provides an empirical test for the theoretical analysis on how the development and application of digital technology can reduce trade costs and promote trade growth. On the other hand, by dividing the actual trade volume into trade potential determined by natural factors and trade efficiency loss caused by human factors, the paper introduces into the HSFG model the importing countries' DED and institutional constraints as explanatory variables of trade efficiency, and more directly clarifies the relationship between various variables and the mechanism of DED promoting trade growth. In addition, based on an analysis of the fact that importing countries' DED may increase the uncertainty of China's export, the paper provides a certain basis for China to formulate relevant policies and ensure steady export growth.

2. Literature Review

2.1. International Trade Efficiency

International trade efficiency is an important factor affecting trade growth. Scholars at home and abroad use the HSFG model to decompose trade growth into trade potential growth and trade efficiency growth. They use trade potential to express the theoretical trade volume that can be achieved when there is no trade resistance, that is,

the "frontier" level of trade, and use trade efficiency to describe the degree to which trade resistance makes the actual trade volume deviate from trade potential, so as to bring the unobservable trade cost caused by "subjective trade resistance" into the analysis. The traditional gravity model often classifies the "artificial resistance" which is difficult to quantify, such as the information cost of buyers and sellers and market system constraints, into stochastic disturbance terms, and assume that their mean value is zero. By introducing the concept of international trade efficiency, it is more realistic to incorporate these influencing factors into the loss of trade efficiency for analysis.

In their research, some scholars assume that international trade efficiency is only a function of time. Shi and Li (2009) assumed that trade efficiency only changed year from year. They used the stochastic frontier gravity model in their analysis and found that China's trade efficiency showed a downward trend. With the introduction of HSFG model, the influence of market factors on international trade efficiency has attracted more and more attention. Some scholars use natural factors such as market size, income level and geographical distance, which are difficult to change in the short term, to determine trade potential, and analyze trade efficiency by taking human factors such as trade agreements, infrastructure level and institutional constraints into consideration. Lu and Zhao (2010) found that the increase of tariff level may reduce trade efficiency, while a high level of democracy and rule of law in the importing country could play a positive role in promoting China's export efficiency. Tan and Zhou (2015) found that free trade agreement (FTA) and better transportation infrastructure can significantly improve the efficiency of China's export to countries along the Maritime Silk Road, while high tariff level, long customs clearance time and low financial freedom may increase the loss of trade efficiency. In addition, some scholars have analyzed the trade potential based on factor endowment. Wu (2003) believed that factor input determines export supply, market environment determines factor allocation, factor input density and market environment determine trade potential. Taking market environment variables into consideration when studying trade efficiency, he analyzed export potential and export efficiency of different regions in China, and found that improvement of infrastructure and increase in government expenditure could improve China's export trade efficiency. Lu and Lian (2011) used factor input to determine the export potential of different provinces, municipalities and autonomous regions in China and analyzed the impact of institutional constraints on export efficiency, finding that infrastructure improvement, government expenditure, market reform, and foreign investment could all promote the export efficiency of China.

2.2. Trade Uncertainty

In recent years, the research on trade growth has been deepened, but there is still insufficient attention to trade uncertainty and trade fluctuation. The importance of

trade uncertainty lies in that intensified trade fluctuation can have a negative effect on economic growth and national welfare. Mendoza (1997) pointed out that increased trade uncertainty may reduce investment, capital accumulation, and consumption-based return on savings, thus slowing down long-term economic growth. Blattman *et al*. (2007) noted that increased trade uncertainty may heighten trade and investment risks, reduce the accumulation of imported capital, and produce a negative impact on economic growth.

Most of the existing studies think that demand effect and trade competitiveness are the main causes of trade fluctuation. Tang and Lin (2012) found that external demand shocks can well explain the fluctuation of export volume and price. Yu (2013) believed that the fluctuation of external demand during the financial crisis is the main reason for the increase of China's trade uncertainty. Li (2009) used factor analysis to find that changes in trade competitiveness are the main cause of China's trade fluctuation. Some scholars have also analyzed the impact of signing FTAs, joining international organizations, and institutional constraints of the market on trade uncertainty. Mansfield (2008) pointed out that joining the WTO and signing FTAs could restrict member countries from taking new trade protection measures and improve their policy transparency, thus reducing trade uncertainty. Wei and Zhang (2018) found that China and its trading partners' accession to the WTO could reduce the price fluctuation of China's imports. As for the market system, Lu and Lian (2011) used the HSFG model to analyze the influence of institutional constraints on the export stability of different provinces, municipalities and autonomous regions in China. Cui and Liu (2017) used the same method to analyze the influence of the market systems of countries along the "the Belt and Road" on China's export uncertainty.

2.3. Digital Economy and International Trade

The influence of DED on international trade has become a hot topic in academic circles. Existing studies generally believe that the application of Internet and ICT can significantly increase the scale of international trade (Freund and Weinhold, 2004; Shi, 2016; Abeliansky and Hilbert, 2017). Some scholars have made analysis from the enterprise level and found that the application of Internet and ICT can enhance the export tendency of enterprises (Li *et al*., 2015; Yue and Li, 2018). Theoretical mechanism analysis is mostly carried out from the perspective of trade cost, and it is believed that the application and development of ICT can reduce the fixed and variable costs in trade, and then promote the growth of trade. Sun *et al*. (2017) proposed that the application of Internet and ICT can effectively overcome the information barriers in trade and reduce the search and matching costs in trade. Sheng *et al*. (2011) held that the development of communication technology reduces the communication cost in trade. Li and Li (2017) believed that the use of Internet can reduce the cost of

recommending new products and exploring new markets. Pan and Xiao (2018) pointed out that Internet can promote global division of labor based on specialization and strengthen market competition, thus forcing enterprises to transform and upgrade and reducing production costs of export enterprises.

3. Theoretical Mechanism Analysis

3.1. DED and International Trade Efficiency

From the perspective of trade cost, this paper analyzes how importing countries' DED affects China's export trade efficiency, focusing on the impact of their DED on the cost caused by "artificial resistance". The following discusses how the development and application of digital technology in importing countries can reduce trade costs in two stages: the establishment of trade relations and the performance of trade contract.

In the stage of establishing trade relations, due to the existence of information barriers, the matching between two trade parties needs certain costs, including search cost, communication cost and credit cost. Existing studies mainly consider the impact of exporting countries' ICT application on information barriers, but in fact, the establishment of trade relations is a two-way process, where importing countries' DED also affects exporting countries' cost of obtaining the market information of importing countries. First of all, the development of Internet and e-commerce platform in importing countries can expand the searchable range of trade information and reduce the cost of searching such information for both the buyer and the seller. The development of search engines also makes the matching of supply and demand information of specific products more efficient. The application of digital technology in importing countries enables enterprises in exporting countries to reduce the cost of displaying and promoting their products through online marketing. Secondly, the development of ICT in importing countries can reduce the communication costs of both parties, and the Internet enables buyers and sellers to communicate in real time without spatial and temporal constraints, thus avoiding the human and the financial costs caused ty traditional "face-to-face" trade negotiations and improving the communication efficiency. Credit cost refers to the cost paid by both parties to obtain each other's credit information. In the era of digital economy, the credit evaluation system based on the digitalization of transaction behaviors has increased the methods and scope of credit evaluation. Countries all over the world have discussed how to build an effective credit evaluation system and relevant standards. The development of Internet and data processing technology has provided new channels for international cooperation and credit information sharing, and reduced the credit cost of both the buyer and the seller.

In the stage of trade contract performance, due to the widespread existence of tariff

and non-tariff barriers, enterprises in exporting countries need to pay institutional costs, especially various compliance costs. In the era of digital economy, all countries are advancing the process of informationization of government affairs, and the development of e-government based on the "Internet plus" strategy is attracting wide attention. The provision of online services in importing countries, such as the construction of IT-based customs clearance platforms, streamlines trade-related compliance procedures, shortens the time of handling such procedures, and improves the processing efficiency, thus reducing the compliance costs of exporters. E-commerce platforms and mobile banking also reduce the cost of payment. Therefore, we put forward the following hypothesis.

Hypothesis 1: The improvement of DED level in importing countries reduces trade resistance and improves trade efficiency.

3.2. DED and Trade Uncertainty

From the perspective of competition, an importing country's DED intensifies its own market competition, which may increase the uncertainty of China's export. First, the Internet and e-commerce platforms in the importing country expand the searchable scope of trading partners, and then increase the number of existing and potential competitors. Secondly, existing studies generally find that investment in information infrastructure improves a country's productivity and innovation capacity. Importing countries' DED, therefore, can increase the productivity of their own domestic enterprises, and at the same time, reduced information exchange cost and learning cost may promote their innovation and R&D activities. As a result, their homogeneous or even upgraded products can further intensify the market competition in importing countries. On the one hand, intensification of competition continuously reduces the price of products; on the other hand, China's export products, usually with low value-added, are rather prone to substitution, so there is very limited room for price reduction. In addition, the domestic production cost is rising, and the dynamic market competitiveness of China's export products is insufficient. Therefore, the intensification of market competition in importing countries is very likely to increase the uncertainty of China's exports.

From a policy point of view, the key to promoting the growth of international trade through DED in importing countries is low-cost and high-efficiency data transmission. Yet, the rules and policies for cross-border data transmission are significantly different from country to country. In recent years, network security incidents have occurred frequently. While all countries are promoting DED in their own territories, some of them are beginning to impose restrictions on cross-border data transmission for the sake of protecting citizens' privacy and national data security. For example, the Russian government requires domestic and foreign companies to store the personal

data of its citizens within Russia; the *General Data Protection Regulations* adopted by the European Union in April 2016 prohibits the transmission of its citizens' personal data to third-party countries that cannot provide adequate protection. Different countries have different rules for cross-border data transmission and for the use of such data, and the conflict of interest between government and enterprises in data use makes the formulation of relevant policies remain in the exploratory stage, which also brings uncertainty to digital technology-based trade growth.

From the perspective of demand, while reducing trade costs and increasing market openness, importing countries' DED also makes them more vulnerable to the impact of world economic fluctuations, thus affecting the uncertainty of China's exports through the demand effect. Mansfield (2008) pointed out that the improvement of market openness may increase the uncertainty of employment, wages and corporate profits. The resulting demand fluctuation is likely to increase the uncertainty of China's export trade. Therefore, we put forward the following hypothesis.

Hypothesis 2: The improvement of DED level in importing countries may increase the uncertainty of China's export trade.

4. Setting of Econometric Model

4.1. Model Specification

In this paper, the HSFG model is used to verify the two hypotheses, and basic structure of the model is as follows:

$$\ln exp_{it} = \ln exp_{it}^{*} - u_{it} \tag{1}$$

$$\ln exp_{it}^{*} = X_{it}\beta + v_{it} \tag{2}$$

Wherein, exp_{it}^{*} stands for the trade potential of China's export to country i in year t; exp_{it} for the actual volume of China's export to country i in year t; u_{it} is a trade inefficiency term used to describe the loss of trade efficiency caused by trade costs. Since trade costs cannot be completely eliminated, it is assumed that the trade inefficiency term obeys the law of truncated semi-normal distribution, that is, $u_{it} \sim N^{+}(\mu_{it}, \sigma_u^2)$. v_{it} is a random error term in the general sense. $v_{it} \sim iidN(0, \sigma_v^2)$ is assumed and u_{it} and v_{it} are mutually independent. X_{it} is an explanatory variable for determining trade potential. Based on the existing research as reference and using the traditional gravity model, here the trade potential is determined by natural factors that are basically unchanged in the short term, such as economic scale, geographical distance and common language, that is:

$$\ln exp_{it}^{*} = c_0 + \beta_1 \ln GDP_{et} + \beta_2 \ln GDP_{it} + \beta_3 \ln pop_{it} + \beta_4 \ln d + \beta_5 comlang + v_{it} \quad (3)$$

Wherein, GDP_{et} and GDP_{it} represent the gross domestic product of China and that of the importing country in year t, respectively, to measure the economic scales of the two sides; pop_{it} stands for the importing country's population in year t, to measure the size of China's export market;[1] d is the geographical distance between the two countries; *comlang* indicates whether the importing country and China share a common language.

In this paper, we use the mean value of trade inefficiency term μ_{it} to measure the loss of trade efficiency caused by "artificial resistance"; and use variance σ_u^2 to measure the trade uncertainty caused by changes in "artificial resistance". We include the importing country's DED index into the estimation equation of the mean and variance of trade inefficiency term, and introduce the relevant institutional indicators of the importing country as control variables for analysis, that is:

$$\mu_{it} = a_0 + \delta_1 NRI_{it} + \delta_2 suf_{it} + \delta_3 tari_{it} + \delta_4 trans_{it} + \delta_5 fta_{it} \quad (4)$$

$$\sigma_u^2 = exp(b_0 + \gamma_1 NRI_{it} + \gamma_2 suf_{it} + \gamma_3 tari_{it} + \gamma_4 trans_{it} + \gamma_5 fta_{it}) \quad (5)$$

Wherein, NRI_{it} is the DED level of country i in year t, which is the core variable in this study; suf_{it} is the customs clearance efficiency of country i in year t; $tari_{it}$ is the weighted average tariff of country i in year t; $trans_{it}$ is the trade transportation infrastructure level of country i in year t; and fta_{it} indicates whether country i has an effective FTA with China in year t. The year effect is controlled in the estimation equations of mean and variance. On the one hand, we control the influence of difficult-to-observe factors that change year from year but that do not change from country to country, such as the periodic fluctuation of the world economy. On the other hand, we control the influence of China's DED and market changes.

4.2. Test Method

In this paper, the maximum likelihood estimation (MLE) method is used to estimate the HSFG model constructed, and the corresponding log likelihood function is:

$$\ln L = -\frac{1}{2}\ln\left(\sigma_v^2 + \sigma_u^2\right) + \ln\left[\varnothing \frac{\ln exp_{it} - X_{it}\beta + \mu_{it}}{\sqrt{\sigma_v^2 + \sigma_u^2}}\right] - \ln\left[\Phi\left(\frac{\mu_{it}}{\sigma_u}\right)\right] + \ln[\Phi(\frac{\mu_{it}}{\sigma_u})] \quad (6)$$

[1] Preliminary regression shows that the influence of China's domestic population is not significant, so the follow-up model does not include China's domestic population.

Wherein,

$$\mu_{it} = (\sigma_v^2 \mu_{it} - \sigma_u^2 (\ln exp_{it} - X_{it}\beta)) / \left(\sigma_v^2 + \sigma_u^2 \right) \tag{7}$$

$$\sigma_u = \sigma_v^2 \sigma_u^2 / (\sigma_v^2 + \sigma_u^2) \tag{8}$$

Wherein, $\varnothing(\bullet)$ and $\Phi(\bullet)$ represent the density function and cumulative distribution function of standard normal distribution, respectively.

4.2.1. Model Applicability Test

The premise of applying HSFG model is the existence of a trade inefficiency term. In this paper, the likelihood ratio test is used to test this. Assuming "$\mathrm{H0}: u_{it} = 0$", the corresponding alternative assumption is "$\mathrm{H1}: u_{it} \neq 0$". Maximum likelihood estimation is carried out for models that satisfy the constraint condition "$u_{it} = 0$" and those to which the constraint condition is not added, to obtain likelihood function values L (H0) and L (H1). Likelihood ratio statistic $LR1 = -2\left[L(\mathrm{H0}) - L(\mathrm{H1}) \right]$ is constructed for testing. If the original hypothesis is rejected, it means there is a non-zero trade inefficiency term, which is estimated using the HSFG model; otherwise, OLS can be used for estimation.

4.2.2. Model Screening

The present study uses the likelihood ratio test to screen the models with different heterogeneous structures. Existing researches have different assumptions about the heterogeneous structure of inefficiency terms. Caudill *et al*. (1995) assumed that the mean of inefficiency terms was constant but their variance was heterogeneous. Battese *et al*. (1995) assumed that the mean was heterogeneous but the variance was constant. Wang *et al.* (2003) assumed that the mean and variance of inefficient terms are both heterogeneous. In this paper, different constraints are imposed on the heterogeneous structure of inefficiency terms, and likelihood ratio tests are carried out for models that meet the constraint condition and those without constraints, and the likelihood function values of different models are compared, so as to choose a more reasonable model structure. The likelihood ratio statistic is $LR2 = -2\left[L(\acute{\mathrm{H}}0) - L(\acute{\mathrm{H}}1) \right]$, where L ($\acute{\mathrm{H}}0$) is the likelihood function value of the model that meets the constraint condition, and L ($\acute{\mathrm{H}}1$) is the likelihood function value of the model without constraints.

4.3. Data Source and Descriptive Statistics

4.3.1. Description of the Core Variable

In this paper, the World Economic Forum's networked readiness index (NRI) is used to measure the DED level of an importing country. As shown in Figure 1, the index is based on three sub-indexes: environment, readiness and application, which respectively evaluate the ICT development environment, the interest and ability to use ICT and the practical application of ICT by major interest groups. Through an analysis of the NRIs of 115 sample countries from 2007 to 2015 (the reference period), it is found that there are obvious differences in DED between countries of different income levels and between different regions. As shown in Figure 2, DED levels in high-income countries are always higher than those in middle- and low-income countries, and their average NRIs are 4.89, 3.56 and 2.93 respectively. Figure 3 describes the differences in NRI between different regions: Africa obviously lags behind other regions, with an NRI growth rate of only 3.52% in the reference period; the NRI of America is higher than that in Africa, with a growth rate of 8.08% in the reference period; the NRI of Asia is at the middle level, but grows rapidly at a rate of up to 12.3% in the reference period, which is significantly higher than that in any other region; the NRI of Europe is lower than that in Oceania, with a growth rate of 8.07% in the reference period. Oceania in this paper only includes two countries, New Zealand and Australia, and their NRI has always been at a high level, with a growth rate of 7.32% in the reference period. It is noteworthy that China's NRI rose from 3.68 to 4.20 in the same period, up 14.1%, significantly higher than the world's average level, which fully reflects the progress made by China in DED in recent years.

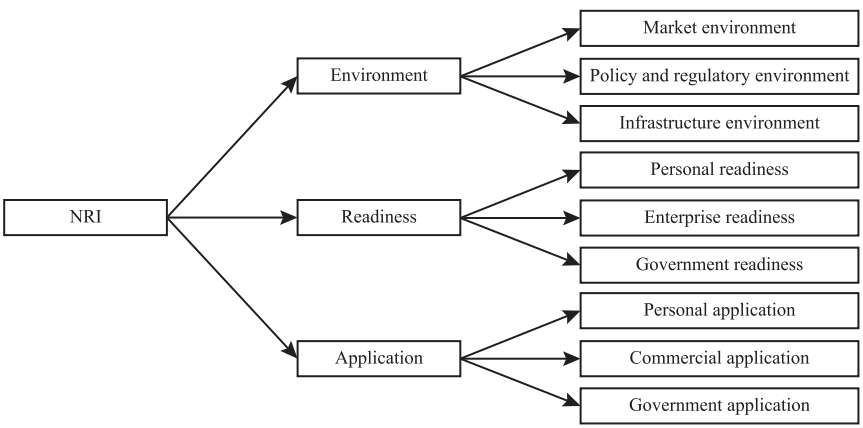

Figure 1. Composition of NRI

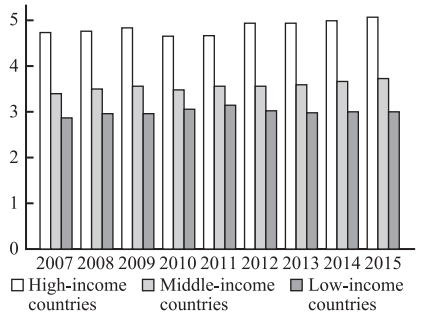

Figure 2. Average NRIs of Countries with Different Income Levels

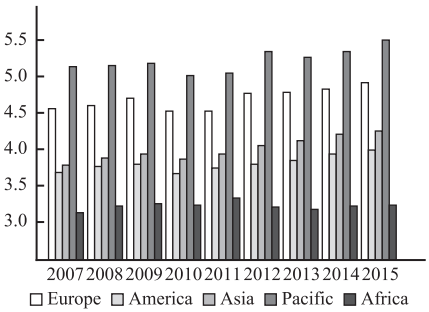

Figure 3. Average NRIs of Different Regions

4.3.2. Description of Other Variables

The variable exp_{it} stands for export volume, including China's export volume to 115 countries and regions in the period of 2007−2015. The data comes from the statistics of General Administration of Customs of China, and the unit is USD 100 million. GDP_{et} and GDP_{it} respectively represent the economic scales of China and the importing country, the data comes from the World Bank, and the unit is USD 10 million. The data of importing country's population pop_{it}, bilateral geographical distance d, whether the two countries share a common language *comlang* and whether there is an effective FTA fta_{it} comes from the gravity database of CEPII, in which *comlang* and fta_{it} are virtual variables, and the unit of pop_{it} is million people. The data of importing country's customs clearance efficiency suf_{it} and trade transportation infrastructure level $trans_{it}$ comes from the World Bank, with a value ranging from 1 (lowest) to 5 (highest). The data of importing country's weighted average tariff $tari_{it}$ comes from the World Bank, and the tariff of each product is weighted by taking its proportion in the total import value as the weight. We take logarithm of the variables of trade volume, population and geographical distance. Table 1 shows the descriptive statistical results of the main variables. Data processing and estimation are completed using STATA 16.0.

Table 1. Descriptive Statistics of Main Variables

Variable	Meaning	Sample size	Mean value	Standard deviation	Max.	Min.
ln*exp*	Export volume	1035	3.175	1.952	8.330	−2.064
lnGDP_e	China's economic scale	1035	13.426	0.377	13.912	12.764
lnGDP_i	Importing country's economic scale	1035	8.971	1.975	14.405	4.381
lnpop_i	Importing country's population	1035	2.53	1.494	7.179	−1.166
ln*d*	Geographical distance	1035	8.975	0.543	9.858	7.063
NRI	Networked readiness index	1035	3.98	0.88	6.040	2.160
suf	Customs clearance efficiency	1035	2.738	0.612	4.210	1.600

Variable	Meaning	Sample size	Mean value	Standard deviation	Max.	Min.
tari	Average tariff level	1035	4.872	3.855	18.610	0.000
trans	Trade transportation infrastructure level	1035	2.816	0.702	4.340	1.530
fta	Whether there is an FTA	1035	0.113	0.317	1.000	0.000
comlang	Whether there is a common language	1035	0.026	0.159	1.000	0.000

5. Econometric Results and Discussions

5.1. Estimation Results of the HSFG Model

Table 2 reports the estimation and test results based on different models. Among them, Models (1) ~ (4) are the estimation results by adding, one by one, the variables in Formula (3) that affect trade potential after controlling the year effect. It can be seen that NRI, which represents DED level, has a significant negative impact on trade inefficiency terms and a significant positive impact on trade uncertainty, indicating that importing countries' DED can significantly improve China's export trade efficiency yet increase trade uncertainty. Model (5) is the estimation result without controlling the year effect. The likelihood ratio statistics *LR*1 and the corresponding *P* values of Models (4) ~ (7) indicate that there is a trade inefficiency term, and that it is more reasonable to use the HSFG model for estimation. Through likelihood ratio statistics *LR*2, the corresponding *P* value and the log likelihood value, it can be found that unconstrained Model (4) is obviously superior to Models (6) ~ (8) to which different constraints are added, showing that the model in which the mean and variance of trade inefficiency term are both heterogeneous is more reasonable in structure. Therefore, the following analysis will be based on Model (4).

It can be seen from the estimation results of trade potential in Model (4) that the economic scales of China and the importing country, $\ln GDP_e$ and $\ln GDP_i$, and the importing country's population $\ln pop_i$ have a positive impact on trade potential, and the impact is significant at the level of 1%, indicating that the higher the income level of both parties and the larger the export market are, the greater the trade potential will be. The coefficient of geographical distance $\ln d$ is significantly negative at the level of 1%, indicating that the farther the distance is, the smaller the trade potential will be. The coefficient of *comlang* that means whether the two countries have a common language is significantly positive at the level of 1%, indicating that two countries with a shorter cultural distance have greater trade potential. These findings are in line with the estimation results of traditional gravity models.

Table 2. Model Estimation and Test Results

	Unconstrained models					$\gamma = 0$	$\beta = 0$	$u_{it} = 0$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Trade potential								
lnGDP_i	0.614*** (18.30)	0.614*** (18.16)	0.650*** (18.40)	0.647*** (23.53)	0.652*** (23.28)	0.681*** (22.42)	0.656*** (26.78)	0.723*** (41.70)
lnpop_i	0.258*** (7.86)	0.258*** (7.66)	0.179*** (4.62)	0.173*** (5.84)	0.172*** (5.64)	0.205*** (7.06)	0.222*** (9.01)	0.124*** (5.38)
lnGDP_e		0.054 (0.01)	0.200 (1.06)	0.515*** (4.94)	0.510*** (8.29)	0.446*** (5.07)	0.398*** (4.88)	0.540*** (7.92)
ln*d*			−0.689*** (−11.46)	−0.564*** (−11.90)	−0.567*** (−11.78)	−0.581*** (−11.00)	−0.565*** (−11.14)	−0.653*** (−13.67)
comlang				1.749*** (11.87)	1.756*** (11.68)	1.943*** (12.83)	1.916*** (12.54)	1.930*** (11.01)
cons	1.852 (1.27)	1.094 (0.01)	1.279 (0.49)	−4.578** (−3.19)	−4.553*** (−4.93)	22.321*** (−7.61)	20.428*** (−8.08)	24.675*** (−11.88)
Trade inefficiency								
NRI	−0.370*** (−5.19)	−0.369*** (−5.16)	−0.316** (−2.94)	−1.722*** (−4.10)	−1.451*** (−4.03)	−1.753** (−2.19)		
fta	−1.145*** (−11.45)	−1.144*** (−11.43)	−0.373** (−2.51)	−1.163** (−2.23)	−1.173* (−1.66)	−4.617 (−0.58)		
suf	0.284** (2.05)	0.284** (2.05)	0.073 (0.41)	0.107 (0.25)	0.272 (0.57)	−0.428 (−0.68)		
cons	6.630*** (4.55)	6.567 (0.75)	2.500*** (5.70)	4.601*** (4.05)	3.786*** (3.39)	6.619** (3.18)	−0.001 (−0.04)	0.000
Trade uncertainty								
NRI	1.125*** (3.65)	1.146*** (3.75)	1.737*** (3.98)	1.797*** (5.99)	1.770*** (5.76)		−1.679* (−1.68)	
fta	0.891** (3.14)	0.906** (3.17)	−8.310 (−1.54)	−1.438 (−0.98)	−1.286 (−0.93)		−4.202 (−1.25)	
tari	−0.122** (−2.66)	−0.126** (−2.73)	−0.129** (−2.14)	−0.144** (−3.17)	−0.160*** (−3.38)		0.001 (0.12)	
trans	−2.250*** (−3.88)	−2.278*** (−3.94)	−2.804** (−3.01)	−2.427*** (−3.91)	−2.212*** (−3.35)		−1.425 (−1.31)	
cons	−1.075 (−1.47)	−1.096 (−1.47)	−3.703** (−2.70)	−1.836* (−1.68)	−1.386 (−1.32)	−2.409** (−2.45)	7.624** (2.07)	0.000
Year	Controlled	Controlled	Controlled	Controlled	Uncontrolled	Controlled	Controlled	Controlled
Sample size	1035	1035	1035	1035	1035	1035	1035	1035
ln*L*	−1234.3	−1234.5	−1190.5	−1128.6	−1136.0	−1154.8	−1159.0	−1217.3
*LR*1				177.368	161.901	125.087	116.523	
P value				0.000	0.000	0.000	0.000	
*LR*2						52.281	60.845	177.368
P value						0.000	0.000	0.000

Note: ***, ** and * mean to be significant at a level of 1%, 5% and 10%, respectively, and values in brackets are "*Z*" values, the same below. Since coefficients of trade inefficiency parts *tari* and *trans*, and the coefficient of trade uncertainty part are not significant, they are not included herein due to limited length of the paper.

The estimation results of trade inefficiency verify Hypothesis 1 proposed in this paper. The coefficient of *NRI* that represents the importing country's DED level is significantly negative at the level of 1%, which shows that the importing country's DED can significantly reduce the loss of trade efficiency and improve China's export efficiency. Improved DED level of the importing country facilitates the establishment of its trade relations with China, and at the same time reduces a series of costs faced by China in the export process, thus improving the efficiency of China's export trade. In addition, the coefficient of *fta* representing whether there is an FTA is significantly negative at the level of 5%. The existence of an effective FTA between China and the importing country can significantly reduce tariff and non-tariff barriers in trade, reduce efficiency losses and help improve China's export efficiency.

The estimation results of trade uncertainty verify Hypothesis 2 proposed in this paper. The coefficient of *NRI* that represents the importing country's DED level is significantly positive at the level of 1%, indicating that DED in the importing country may aggravate the trade fluctuation of China's exports to that country. The importing country's FED reduces trade cost, and intensified competition from third-party countries and the importing country itself increases the uncertainty of China's exports. Secondly, with the continuous development and application of digital technology, the trade market is being digitalized, and related policies and enterprises' adaptation are uncertain. The emergence of new issues such as network security and cross-border privacy protection, and the reshaping of interest patterns lead to frictions between countries, for which international coordination is necessary and ongoing. As can be seen, while global DED brings new opportunities to international trade, it is also reshaping the trade pattern and bringing new challenges to China's exports. At the same time, the coefficient of weighted average tariff *tari* is significantly negative at the level of 5%, which shows that increased tariff level in the importing country may reduce the uncertainty of China's exports. As a trade barrier, the importing country's tariff may increase trade cost, and its effect is opposite to that of DED. Trade transportation infrastructure level *trans* is significantly negative at a level of 1%, and can reduce the uncertainty of China's exports, the reason for which may be that a higher level of trade transportation infrastructure in the importing country is conducive to China's diversified market expansion in that country, thus reducing the risk and fluctuation of trade.

5.2. Differences between Countries with Different Income Levels

According to the classification standard of the World Bank, importing countries are divided into high-income countries and low/middle-income countries[1] for group-by-

[1] Because there are only 14 low-income countries in the sample, MLE estimation is difficult to converge under the assumption of truncated semi-normal distribution, so low-income countries and middle-income countries are classified into one group for the convenience of analysis.

group regression, and the results are shown in Columns (1) and (2) of Table 3. It can be found that the impact of DED in importing countries with different income levels on trade inefficiency term is significantly negative at the level of 1%, which is consistent with the overall estimation results. And through the coefficient, it can be found that DED in low/middle-income countries can significantly improve the efficiency of China's export to these countries. Estimation results of the trade uncertainty are basically consistent with the overall estimation results, and DED in all importing countries with different income levels increases the trade uncertainty of China's export. In the reference period, the average trade efficiency of China's export to low/middle-income countries is always lower than that to high-income countries, and DED can effectively reduce the difference in trade efficiency between high-income countries and low/middle-income countries. It can be seen that global DED is conducive to creating a fairer trade environment and providing new opportunities for low/middle-income countries to improve their market attractiveness.

Table 3. Group-by-Group Regression and Alternative Variable Regression

	Different income levels		Different time intervals				Alternative variable
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Trade inefficiency							
NRI	−0.447***	−1.673***	−1.689***	−0.772***	−1.416**	−1.251**	
	(−6.34)	(−4.04)	(−4.17)	(−3.72)	(−3.26)	(−2.51)	
ituse							−0.130**
							(−2.21)
fta	−0.486***	−0.897	−1.185**	−0.147	−1.006	−0.274	−1.039*
	(−3.90)	(−1.64)	(−2.75)	(−0.96)	(−1.56)	(−0.83)	(−1.71)
suf	0.418**	0.204	−0.134	−0.113	0.492	1.487**	−0.366
	(2.68)	(0.41)	(−0.26)	(−0.38)	(1.02)	(2.30)	(−0.47)
trans	−0.577**	0.333	0.409	−0.038	0.081	−0.095	−0.377
	(−3.04)	(0.80)	(0.90)	(−0.13)	(0.22)	(−0.20)	(−0.66)
cons	4.506***	3.695**	4.982***	3.350***	3.356**	0.463	2.735***
	(10.74)	(2.80)	(3.89)	(5.33)	(2.90)	(0.36)	(3.72)
Trade uncertainty							
NRI	2.689***	2.251***	2.313***	2.093***	1.826***	1.329**	
	(5.71)	(5.04)	(4.59)	(4.25)	(5.90)	(2.89)	
ituse							0.072***
							(6.48)
tari	−0.443**	−0.240***	−0.145**	−0.216**	−0.171**	−0.194**	−0.037
	(−2.40)	(−4.12)	(−2.15)	(−2.78)	(−3.21)	(−2.94)	(−0.85)
trans	−1.999**	−2.252**	−3.424**	−3.082**	−2.061**	−1.750**	−2.769**
	(−2.54)	(−3.02)	(−2.79)	(−2.86)	(−3.11)	(−2.24)	(−3.28)
cons	−8.611***	−0.706	−2.710*	−2.377*	−1.301	1.695	2.112*
	(−5.28)	(−0.31)	(−1.74)	(−1.72)	(−1.19)	(1.02)	(1.88)
Year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Sample size	396	639	460	575	805	460	987
ln*L*	−291.5	−710.1	−496.5	−629.0	−878.7	−499.3	−1059.7

Note: Limited by the length of the paper, the estimation results of trade potential part are not listed in Table 3, as is the same in Table 4. Interested readers can request for these results by mail. The coefficients of trade inefficiency *tari* and trade uncertainty *fta* and *suf* are omitted here because they are not significant.

5.3. Robustness Analysis

5.3.1. Regression for Different Time Intervals

In order to analyze whether importing countries' DED level has a robust influence on China's export trade efficiency and trade uncertainty in different time intervals, the samples are divided into four groups in different time intervals for regression, and the results are shown in Columns (3) ~ (6) of Table 3. Specifically, Column (3) is from 2007 to 2010, with an interval of 4 years; Column (4) is from 2008 to 2013, with an interval of 6 years; Column (5) is from 2009 to 2015, with an interval of 7 years; and Column (6) is from 2012 to 2015, which is mainly intended for analyzing the robustness in the recent 4 years. On the whole, in different time intervals, the influence of importing countries' DED on China's export trade efficiency and trade uncertainty is relatively robust.

5.3.2. Regression of Alternative Variable

DED is inseparable from the application of Internet. According to Metcalfe's law, the value of a network is equal to the square of its number of nodes. Therefore, the proportion of Internet users in the total population of the importing country *ituse* is used as an alternative variable to measure the DED level of the importing country. The data comes from the World Bank, and the estimation results are shown in Column (7) of Table 3. It can be seen that an increase in the proportion of Internet users in the importing country can significantly reduce the loss of trade efficiency and increase the uncertainty of trade. Therefore, the regression results obtained by using alternative variable are still robust.

5.3.3. Discussion on Endogenous Problems

If important variables are omitted or reverse causality exists in the analysis, serious endogenous problems will occur, which will affect the consistency of estimation results. In the benchmark model of this paper, the year effect is controlled to avoid the missing variables which are only related to the year and do not change with the importing country, such as China's DED level, domestic policy changes and global economic fluctuations. However, the omission of market environment variables of importing countries may still bring endogenous problems. Therefore, this paper uses the economic freedom indexes published by The Wall Street Journal and The Heritage Foundation to group sample countries because countries with similar economic freedom indexes have similar market environments, so as to reduce the influence of market environment differences of sample countries in the same group. The estimation

results are shown in Columns (1) ~ (3) of Table 4. It can be seen that DED of importing countries with different levels of economic freedom can significantly reduce the loss of trade efficiency of China's export, and at the same time, its impact on trade uncertainty is still significant.

As far as reverse causality is concerned, the impact of China's export efficiency and export uncertainty on importing countries' DED is very limited. However, for the sake of robustness, importing countries with greater trade resistance may also establish new trade advantages by strengthening DED, and attract foreign goods to enter their domestic markets. In order to reduce the impact of reverse causality, this paper takes importing countries' DED levels with one lag phase and two lag phases as explanatory variables, and substitutes them into the model for regression. The lag phase of importing countries' DED level is a predetermined variable, and the current efficiency and uncertainty of China's export trade can not affect the previous DED of importing countries. The estimation results are shown in Columns (4) ~ (5) of Table 4, which indicate that the impact is still significant.

In addition, *NRI*, which is used in this paper to measure importing countries' DED level, contains sub-indicators of ICT development environment and policies in these countries, which may be related to other market environment variables not included in the model, resulting in endogenous problems. Meanwhile, although regression with the lag phase of *NRI* can reduce the impact of reverse causality, it misses the current information. Therefore, the instrumental variable method is used for further analysis, and the proportion of the population with a secondary education background in the importing country and the number of secure network servers are used as instrumental variables of the endogenous explanatory variable *NRI*. Both of them are sub-indicators in the *NRI* index system, so they have strong correlation with *NRI*, while education level and number of servers have no direct relationship with market environment. China's export efficiency and uncertainty may not have a direct impact on the education level and the number of servers in the importing country, so it meets the requirements of relevance and exclusivity of instrumental variables.

The estimation results of instrumental variable method are shown in columns (6) ~ (8) of Table 4. All the test results show that the model is endogenous, and the selection of instrumental variables is reasonable, so no further details will be provided hereinafter. In column (7), the robust standard error is used to avoid the influence of heteroscedasticity, and the limited information maximum likelihood (LIML) method insensitive to weak instrumental variables is used for estimation. In column (8), the possible autocorrelation in the same importing country is further considered, the trade inefficiency term is estimated by using the "importing country" as the cluster variable, and the generalized moment estimation method (GMM) is used for regression. All the results show that the influence of importing countries' DED level is still robust after considering endogenous problems.

Table 4. Results of Endogeneity Analysis

	Different market environments			Lag phase		2SLS	LIML	GMM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Trade inefficiency								
NRI	−0.472*** (−4.05)	−1.483*** (−3.66)	−0.529** (−2.49)	−1.690*** (−3.67)	−1.318*** (−4.47)	−0.478*** (−3.73)	−0.478*** (−3.46)	−0.462*** (−3.65)
Trade uncertainty								
NRI	7.320*** (3.68)	1.800*** (3.42)	3.107*** (4.95)	1.819*** (5.82)	2.184*** (6.44)	1.996*** (27.25)	1.995*** (26.57)	2.000*** (27.31)
Year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Sample size	340	340	340	920	770	963	963	963

Note: For trade inefficiency and uncertainty, only the estimation results of the core variable *NRI* are listed in the table, due to limited length of the paper.

5.4. Analysis of Trade Efficiency

After estimation of Model (4), the trade efficiency of China's exports to 115 sample countries is obtained according to Formula (9).

$$TE_{it} = \frac{\exp(X_{it}\beta - u_{it})}{\exp(X_{it}\beta)} = \exp(-u_{it}) \tag{9}$$

Figure 4 shows the distribution of trade efficiencies of China's exports to sample countries from 2007 to 2015 (the reference period). It can be seen that most of the trade efficiencies are between 70% and 90%. In this period, China's average export efficiency is 73%, specifically, 72.5% in 2007 and 73.5% in 2015. It can be seen that in these nine years, China's export trade efficiency improved on the whole, but the increase was very limited. At the same time, the efficiency of export to some countries is still very low, and the trade potential is far from being fully realized. For example, the average trade efficiency of China's exports to Chad is only 25.2%, which shows that there is still much room for improvement in global trade efficiency.

Figure 5 is a sequence diagram of China's export efficiency. It can be found that there are obvious differences in the efficiency of China's exports to countries with different income levels. The average efficiency of export to high-income countries in the reference period is about 81.5%, which is always higher than that of low/middle-income countries and that of all samples. The average efficiency of export to middle-income countries is 71.4%, while that to low-income countries is always the lowest, about 52.9%. At the same time, it is found that in 2009, the efficiency of China's export to sample countries as a whole and that to countries with different income

levels both decreased significantly, which may be caused by the deterioration of global economic environment caused by the international financial crisis and other factors. In addition, the efficiency of export to high-income countries showed a downward trend on the whole, from 84.2% in 2007 to 78.7% in 2015, a decrease of 6.5 percentage points. In recent years, trade protectionism has been on the rise. Under the influence of "anti-globalization", high-income countries have introduced a series of protectionist measures, which have increased the cost and decreased the efficiency of China's export. The efficiency of export to middle-income countries increased by 4.6%, and that to low-income countries increased most obviously, up 27.5 percentage points from 2015 to 2007. In recent years, the information infrastructure of low/middle-income countries has been continuously improved, and their DED has made China's export efficiency continuously improve. Since the Belt and Road Initiative (BRI) was put forward, China has continuously strengthened connectivity and economic cooperation with BRI-participating countries. The construction of transportation infrastructure and trade cooperation have created a better business environment for these countries, which not only reduced the loss of trade efficiency of China's export, but also enabled participating countries to reap abundant benefits from cooperation.

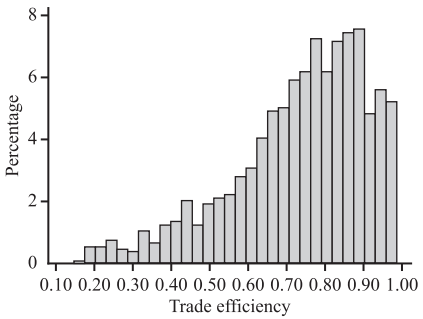

Figure 4. Distribution of Trade Efficiencies

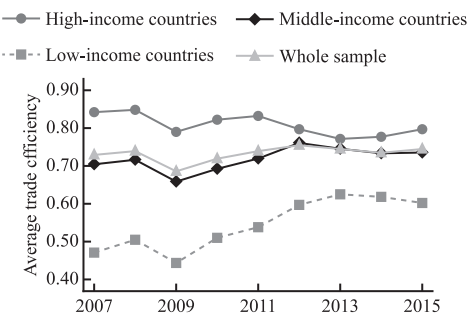

Figure 5. Sequence Diagram of Trade Efficiency

6. Conclusions and Suggestions

DED has triggered a series of changes in the international trade market. The development and application of digital technology in importing countries can reduce China's cost of obtaining market information, finding trading partners, establishing trade relations and fulfilling delivery obligations, thus reducing the "artificial resistance" caused by information barriers and market system constraints in importing countries and improving the trade efficiency of China's exports. At the same time, the reduction of trade cost also aggravates the market competition in importing countries, and the competition from other countries and from importing countries themselves increases the uncertainty of China's export trade. The uncertainty of protective policies

of importing countries on cross-border data transmission and network security can also aggravate the uncertainty of China's export trade that is based on digital technology. DED improves the market openness of importing countries, yet makes them more susceptible to the fluctuation of world economy. The resulting demand shocks can increase the fluctuation of China's export trade. On the basis of theoretical mechanism analysis, this paper makes an empirical analysis based on the data of China's exports to 115 countries from 2007 to 2015 by using the HSFG model, and finds that DED can significantly reduce the loss of trade efficiency and improve the efficiency of China's exports, and this effect is more obvious for China's exports to low/middle-income countries. At the same time, the trade uncertainty of China's exports can increase significantly with the improvement of importing countries' DED level.

In recent years, countries around the world have gradually realized that DED may become the source of new competitive advantages. Since importing countries' DED can effectively improve China's export efficiency, China needs to speed up cooperation in DED with other countries, including strengthening cooperation in the construction and sharing of digital infrastructure with BRI-participating countries during the implementation of BRI, so as to create a better trade environment, improve China's export efficiency, raise the welfare level of these countries, and achieve the strategic goal of win-win development. However, with deepened integration of the world market, the transmission of economic fluctuations is more rapid. Facing the trade uncertainty brought by global DED, while promoting the reshaping of international trade rules in the era of digital economy, China should strengthen guidance for the transformation and upgrading of domestic enterprises to enhance their international competitiveness. At the same time, it should make more efforts to improve the anti-risk capacity of domestic enterprises. For example, the Chinese government should expand the coverage of export credit insurance so as to ensure that domestic enterprises can safely collect payment and smoothly pass through the digital transition period, and that China can establish a new competitive advantage in the global DED wave.

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