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Export profitability and firm R&D: on China's export diversification under trade war

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ABSTRACT

China has become the world's largest export economy and the Sino-US trade war since 2017 has brought about serious implications for its foreign trade. To mitigate the effect of the trade war, China has tried to diversify exports from the US to other major trade partners. This paper aims to study the impact of the trade war on the export profitability of Chinese manufacturing firms and examine the role of firm R&D activities in their export diversification process. It is found that under the trade war, firm export profitability with intensive exports to the US declined, but the negative shock is less potent for firms with more R&D activities. In addition, the resilience of R&D-intensive firms stems from two distinctive abilities, i.e., the ability to attract new customers in different alternative markets and the ability to optimize the composition of market niches.

1. Introduction

China has emerged as the world's largest exporter since 2012. According to the UN Comtrade data, its export value to the US in 2017 was $505.60 billion, accounting for 21.6% of the latter's imports, making China the largest US import source country. China's steady and prodigious export expansion is inseparable from the intensive R&D activities at the firm level. The relentless pursuit of national technological innovation strategies, such as "*China's Innovation-Driven Development Strategy*" and "*Made by China 2025*″, has evidently enabled the country to gradually gain international competitiveness of export across the globe. In particular, China has made enormous effort to move up the global value chain, becoming a credible competitor of the US and the EU in many high-tech industrial categories of export goods. Consequently, the original high-level complementarity of bilateral trade between China and the US has been gradually evolving into a competitive relationship for an ever-rising number of manufacturing products, provoking the aforementioned Sino-US trade war triggered by the Trump administration since 2017 under the excuse of rising bilateral trade imbalances.

Developed economies, such as the US, are increasingly concerned about the effect of an import shock from China on their economic development, including the impact on their industrial structure (David et al., 2013), enterprise innovation (Liu, 2013; Aghion et al., 2014; Dorn et al., 2020), sustainable corporate operation (Bernard et al., 2006), and employment (Mion et al., 2013; Autor et al., 2014; Greenland et al., 2016; Hombert et al., 2018).

Since 2007, China has been the most subject to "Section 337″ investigation by the US.[1] According to Guo et al. (2018) and Bergsten (2018), the US government believes that certain tendencies among Chinese companies regarding intellectual property rights and investment have hindered the technological progress, harmed the interests, and strained the domestic market of the US. De Rassenfosse and Raitieri (2022) argue that the Chinese government's IPR protection practices in strategic technology areas may lower incentives for global innovation, hurt the international trade of technology-intensive goods, and harm

The authors remain solely responsible for any error or omission herein.

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[1] As indicated by the authors, the data come from the US International Trade Commission (ITC): https://pubapps2.usitc.gov/337external/. "Section 337" most often involves claims regarding intellectual property rights, including allegations of patent infringement and trademark infringement by imported goods.

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foreign firms. Therefore, out of concern to protect domestic export and reduce the trade deficit between the US and China, in 2017,[2] the Office of the United States Trade Representative (USTR) invoked Section 301 of the US Trade Act to boycott some trade activities with China and imposed high tariffs on some Chinese import goods, particularly in the high-tech (R&D-intensive) industrial sectors. Since then, the Sino-US trade friction has escalated into a full-scale trade war. Relevant studies show that the trade war has seriously undermined the two economies in different aspects (Tu et al., 2020), resulting in an increase in unemployment (Acemoglu et al., 2018; Fort et al., 2018), an imbalance in industrial and trade structures (Tu et al., 2020), and a decline in social welfare (Amiti et al., 2019; Fajgelbaum et al., 2020; Ng, 2020; Cavallo et al., 2021).

In theory, the trade war can be regarded as a punishment for the Chinese R&D-intensive firms and products imposed by the US to protect its domestic industries. However, the universal imposition of trade tariffs against Chinese high-tech manufactural goods can lead to complicated reactions of export firms with serious implications on export performance (profitability) for different types of firms with respect to the level of technological innovation represented by their R&D intensity. It is expected that firms with higher R&D intensity would be more competitive in export as they are more able to find alternative export markets to cope with the trade shock and circumvent trade barriers. Previous studies have also shown that R&D can increase the probability of firms participating in exports, especially firms in the high-tech industries (Sanyal, 2004; Motobbio et al., 2005; Becker and Egger, 2013). Amid the Sino-US trade war (hereafter, the trade war), it is expected that technological innovation ability of export firms may affect their export profitability through export diversification away from the US to different alternative markets. The extent to which and how R&D intensity can mitigate the negative impact of the trade war on export profitability through export diversification is an interesting theoretical issue as well as an important empirical concern of academic research, which is the main focus of this paper based on the empirical evidence of the Chinese firms listed in the A-share stock markets in Shanghai and Shenzhen.

Export diversification is an important strategy to cope with the trade war and circumvent trade barriers. To optimize the export geographical composition and reduce the over-dependency on a single market, Chinese manufacturing firms have endeavored to sustain export expansion through diversifying exports away from the US to other foreign markets, particularly to the EU, ASEAN, Africa and other economies along with the "Belt and Road Initiative" to mitigate export risk and enrich the multilateral trade system across the globe. According to the United Nations Trade Database statistics, the US, EU, and ASEAN are China's three most important trade partners. Evidently, the EU and ASEAN are, by nature, the most important alternative destinations for China's exports if firms are forced to move away from the US. However, these two markets have obvious differences regarding the level of economic development, consumption structure, and the global value chain division. Therefore, in the process of export diversification, Chinese firms need to choose these two alternative markets based on their relevant comparative advantages suited to the local market conditions and consumer preferences. In theory, consumers in the EU are expected to demand relatively more high-tech products compared to their ASEAN counterparts. In response, export firms with higher R&D intensity are expected to export more to the EU than to the ASEAN markets. In contrast, firms with relatively low level of R&D may export more to the latter than to the former market. Whether this theoretical conceptualization is valid, however, needs to be testified empirically.

Previous studies in this field have seldom focused on the specific background of international trade friction and export trade diversification. However, these issues have far-reaching influences on the global economy and trade. Accordingly, we consider the 2017 Sino-US trade war as a good and appropriate experiment for research. We first examine the export profitability changes of the sample firms to the US before and after the trade war and how firm-level R&D activities may affect this process. We then study how firm R&D activities affect the export diversification pattern away from the US to the EU and ASEAN to verify the theoretical conceptualization posited above.

More specifically, the trade war reduces the export profitability of the Chinese manufacturing firms in the US market due to tariff increase and exchange rate transmission. However, this negative impact can be mitigated by R&D intensity at the firm level. In other words, firms with intensive R&D activities are more resilient to external shocks caused by the trade war. A logical explanation for this mitigation effect lies in the fact that firms with high R&D intensity are more likely to diversify their exports away from the US to other alternative markets such as ASEAN and the EU than those with low R&D intensity. We find that in the trade diversification process, Chinese firms' export profitability in ASEAN ascends but export profitability in the EU declines, as a result of the trade war. However, whether in the ASEAN or EU markets, Chinese firms with more intensive R&D are more competitive and profitable than their low R&D counterparts, because they are more capable of attracting new customers in alternative markets and optimizing the geographic composition of market niches in the global industrial division.

This paper has three potential contributions to the extant literature. Firstly, it elaborates and testifies a hypothesis that firm's ability in technological innovation can mitigate the adverse effect of the trade war on export profitability. This is because technological innovation can enhance the resilience of export firms to withstand the trade shock through export diversification and circumvent trade barriers. Secondly, it proposes and verifies two important mechanisms by which firm technological innovation creates values during the export diversification process, i.e., an induced ability to attract customers in new markets (first mechanism) and an induced ability to adjust and optimize the composition of market niches in the global industrial division (second mechanism) as a result of technological innovation. In addition, the "quasi-natural experiment" on the trade war also allows us to compare and identify which of the above-mentioned mechanisms is more dominant than the other in export diversification. Thirdly, while most extant studies only focus on the impact of export competition from developing countries (such as China) on firms in the developed (import) economies such as the US (Bernard et al., 2006; Hombert et al., 2018; Dorn et al., 2020), this study focuses on how export competitiveness affects China's export strategy and firm performance in response to changes in the external trade environment.

The remainder of this paper is organized as follows. Section 2 presents theoretical analysis and hypotheses. Section 3 describes research methodology and data. Section 4 explains empirical results. Section 5 discusses and verifies the mechanisms through which firm technological innovation affects export diversification and firm performance. Section 6 conducts some further tests, including heterogeneity and robustness tests. Section 7 concludes.

2. Theoretical analysis and hypotheses

2.1. Hypothesis based on the main targets of the trade war

Bilateral trade in goods and services between China and the US has expanded continuously since China's accession to the WTO in 2001. The volume of Sino-US bilateral trade rose from US$80.6 billion to US $635.97 billion in 2017, a nearly eight-fold rise over 16 years. The trade imbalance against the US (deficit) also rose sharply over time. The level of the US trade deficit with China reached US$375.2 billion in 2017. In March 2017, the US imposed penalties on China's telecommunications firms for violating its export control policies and further restricted US

[2] In August 2017, Trump signed an administrative memorandum to conduct 301 investigations in China. The information comes from Xinhuanet: http://www.xinhuanet.com/world/2017-08/15/c_1121482364.htm.

suppliers from exporting parts and accessories to them, causing a disruption to the supply chain of *Computer, Communication,* and *Other Electronic Equipment Manufacturing* industry. In August 2017, the US government signed an administrative memorandum on Section 301 investigation, imposing additional import tariffs against some targeted categories of manufacturing goods, particularly those made by the high-tech industrial sectors, triggering an unprecedented and large-scale trade war. In January 2018, the US government announced 4-year and 3-year global safeguard measures for imported large washing machines and photovoltaic products from China, imposing import tariffs between 30% and 50%. In May of the same year, the US government announced that it would impose a 25% tariff on $50 billion worth of "important industrial technology" imported from China, covering steel products, aluminum products, medical drugs, chemical compounds, rubber products, and other commodities related to the "*Made by China 2025*″ strategy. The Sino-US trade war broke out fully.

The trade war must have inevitably impacted the exports of relevant Chinese firms to the US, especially in export-intensive industries where the US may feel more threatened. First, in terms of tariff increases, the goal of the US in launching a trade war is to limit China's exports to the US and reduce the bilateral trade deficit. The resulting high export tariffs and trade costs may increase prices including tariffs of Chinese exports, because exporting firms tend to pass through additional tariffs into US domestic prices without affecting the prices received by exporters (Amiti et al., 2019; Fajgelbaum et al., 2020; Cavallo et al., 2021). This reduces the export competitiveness of Chinese products. In response to an uncertainty shock, export firms must disproportionately reduce production (Jiang et al., 2023) and cut orders of foreign inputs. However, high fixed costs cannot be reduced (Novy and Taylor, 2020), seriously damaging the export profitability of Chinese firms, especially the export-intensive ones, to the US. Existing studies also suggest that destination tariffs negatively affect firm-level exports (Xu et al., 2021).

Second, in terms of exchange rate transmission, the US implements trade protection by raising tariffs on imports, and China takes relevant measures to counter trade threats, rendering Sino-US tariffs full of uncertainty. The foreign exchange market is inevitably affected by tariff fluctuations (Xu and Lien, 2020). Exchange rate fluctuations can negatively affect international trade. In a context where firms are risk-averse, exchange rate risk increases trade costs and reduces gains from international trade (Ethier, 1973). For example, if the share of imported inputs in production is higher for firms, depreciation of the national currency increases their production costs through increased import costs. Furthermore, any additional cost (transport, marketing, advertising, insurance)—not substitutable to production—paid in the local currency would also be affected by changes in the exchange rate, further affecting firm profitability. In response to this uncertainty shock, exporting firms raise prices or disproportionately reduce production and cut foreign input orders. Berman et al., al.(2012) find that large movements in nominal and real exchange rates have a negative effect on aggregate variables such as export prices and volumes. However, high fixed costs that cannot be reduced generate leverage, seriously damaging the export profitability of Chinese firms with declining export volumes.

To understand the theory underpinning the trade war and the empirical consequences on the Chinese export firms, we present our first hypothesis below.

Hypothesis 1: The trade war reduces export profitability of the Chinese firms with intensive exports to the US. This is because the US targets them more disproportionately than others in the trade war.

2.2. Hypothesis based on the ability to manage the trade war

The endogenous growth theory emphasizes the effect of technological innovation on foreign trade. It indicates that it is a key factor in determining the competitive advantages of firms and countries (Grossman et al., 1991). In the trade theory, technological level, factor endowment, and enterprise-scale constitute the foundation of international trade, and technological innovation is a crucial factor affecting export performance. Technology gap theories further highlight the role of technology and state that trade may be caused by the existence of some technical knowhow in a country not available elsewhere, although there may be no international differences in the relative endowments of production factors (Posner, 1961). Wide technological and organizational differences ultimately shape trade patterns within sectors across countries and their dynamics. This property also applies at the micro-firm level, where trade flows are primarily driven by the absolute advantages of the company, which in turn stems primarily from widespread technological asymmetries between firms that relate to the capability of some firms to produce innovative commodities (i.e., commodities that other firms are not yet capable of producing, irrespective of relative costs) and to use process innovations more efficiently or more quickly, thus reducing input coefficients (Dosi et al., 2015). This forms a "virtuous circle" of gains from technology among success in introducing new products, export growth, and higher profits (Guarascio and Pianta, 2017; Bogliacino et al., 2017). Therefore, the export competitiveness of enterprises is significantly influenced by technological innovation (Schumpeter, 1942; Aghion et al., 2001).

Extant studies show that technological innovation helps firms to overcome trade obstacles, such as transaction costs, and gain strong competitiveness in export in three ways: improving firm productivity (Melitz, 2003; Bernard et al., 2003; De Rassenfosse et al., 2022), raising product quality (Hallak et al., 2011; Crozet et al., 2012; Kugler, 2012), and enriching product differentiation (Mayer et al., 2014; Halpern et al., 2015).

Although the trade war that started in 2017 aimed at firms that were more R&D-intensive, the R&D capabilities of these firms could help them to produce higher value-added and more competitive products, which was conducive to export diversification. Firms with higher R&D intensity are more flexible in the process of international trade shift and more capable of dealing with the pressure of the trade war, thanking to the following two abilities induced by technological innovation.

The first ability (mechanism) of export firms induced by innovation is to attract new customers in alternative trade economies. In other words, firms with higher R&D intensity should be more competitive and would find it easier to enter new markets to mitigate the negative shocks of tariff increase and exchange rate fluctuations triggered by a bilateral trade war. As for export diversification away from the US to other alternative economies, Chinese firms are more likely to choose the developed economies with similar development levels and consumption structures to the US, such as the EU.

The second ability (mechanism) induced by innovation is to optimize the geographical trade composition in an export diversification process as a result of the trade war (Jorgenson et al., 2016). Amid the trade war, Chinese manufacturing firms with more intensive R&D may adopt a new trade strategy more quickly to mitigate the negative shock, because they can enter a more value-added industrial division more easily in trade collaboration. For example, they may export intermediate goods or parts to the non-trade war areas and have the final products assembled there to avoid increased export tariffs. To be able to do so, firms need to develop a high-level technological capability through R&D and diversify their exports away from the US to the alternative economies that they have obvious comparative advantage such as ASEAN rather than the EU. In other words, Chinese export firms are more likely to export more to ASEAN than to the EU as an alternative market for the consideration of relative technological advantage.

These two abilities can help firms engaged in innovative activities circumvent penalty duty through export diversification more easily and react to depreciation by increasing their export volume to regions other than the US, thus absorbing the influence of tariff increases and exchange rate changes to some extent. They make these firms more productive, have higher-quality products, have larger market shares in a sector, and thus face lower demand elasticity (Berman et al., 2012).

Table 1
Variable definitions.

Variable symbol	Definitions/calculations
ROA	The ratio of net profits over total assets
$MS_{m,j,t}$	Share of industry *j* and country *m* in China's total exports in time *t* defined in See Eq. (3)
NTB	Industrial export competitiveness. See Eq. (4)
Innovation	The ratio of R&D expenditures over total assets
Size	The natural logarithm of total assets
Lev	The ratio of total liabilities over total assets
Age	The natural logarithm of the current year minus firm establishment year plus one
Inv	The ratio of net cash generated from disposal of investment assets over total assets
NA	The ratio of total assets minus cash and cash equivalents over total assets
Capex/PPE	The ratio of capital expenditure over PPE (Property, Plant, and Equipment)
CF	The ratio of net cash flow from operating activities over total assets

In brief, high R&D intensity firms have larger profit margins and stronger resilience to external trade shocks. They have two different technologically induced abilities to diversify export away from the US to different alternative trade economies, depending on the comparative advantages of the export firms with respect to the respective markets. Based on this theoretical discussion, we present another hypothesis below.

Hypothesis 2: The negative shock of the trade war to export profitability of Chinese firms can be mitigated for firms with more intensive R&D. This is because technological innovation enables firms to diversify exports either to the developed economies such as the EU which has similar technology and consumption preference to the US, or to the developing economies such as ASEAN where Chinese export firms enjoy relatively more competitiveness.

3. Research design

3.1. Models and variables

The basic profitability-innovation model proposed byDorn et al. (2020) is modified to include export intensity to measure firm export profitability to the US before and after the trade war and the effect of corporate R&D in the process. Taking the trade war as an exogenous shock in a quasi-natural experiment, we regress firm profitability (*ROA*) on the triple interaction among export intensity (*MS* or *NTB*), the trade war (*Treat*), and R&D intensity (*Innovation*), as shown in the DDD (triple difference) models (1) and (2).

The coefficient β_1 reflects firm export profitability, indicating the profitability contributed by each unit of export competitiveness to the US. The larger the coefficient, the higher the export profitability in the US. Coefficient β_4 reflects the impact of the trade war on firm export profitability in the US. If it is negative, it means that the trade war induces a negative shock to firm export profitability. Coefficient β_5 indicates the effect of R&D on firm export profitability in the US before and after the trade war. If β_5 is positive, it means that after the start of the trade war, R&D intensity plays a role in promoting firm export profitability, alleviating the adverse impact of the trade war on firm profitability.

$$\begin{aligned} ROA_{i,j,t} &= \partial + \beta_1 MS\_USA_{j,t-1} + \beta_2 Treat_{j,t} + \beta_3 Innovation_{i,j,t-1} \\ &+ \beta_4 MS\_USA_{j,t-1} \times Treat_{j,t} + \beta_5 MS\_USA_{j,t-1} \times Treat_{j,t} \times Innovation_{i,j,t-1} \\ &+ \beta_6 MS\_USA_{j,t-1} \times Innovation_{i,j,t-1} + \beta_7 Treat_{j,t} \times Innovation_{i,j,t-1} \\ &+ Controls_{i,j,t-1} + v_j + w_t + \varepsilon_{i,j,t} \end{aligned} \tag{1}$$

$$\begin{aligned} ROA_{i,j,t} &= \partial + \beta_1 NTB\_USA_{j,t-1} + \beta_2 Treat_{j,t} + \beta_3 Innovation_{i,j,t-1} \\ &+ \beta_4 NTB\_USA_{j,t-1} \times Treat_{j,t} + \beta_5 NTB\_USA_{j,t-1} \times Treat_{j,t} \times Innovation_{i,j,t-1} \\ &+ \beta_6 NTB\_USA_{j,t-1} \times Innovation_{i,j,t-1} + \beta_7 Treat_{j,t} \times Innovation_{i,j,t-1} \\ &+ Controls_{i,j,t-1} + v_j + w_t + \varepsilon_{i,j,t} \end{aligned} \tag{2}$$

where *Treat* is a dummy variable that equals 1 when industry *j* is affected by the trade war in year *t* and 0 otherwise. For example, in March 2017, the US imposed penalties on Chinese telecommunications firms for violating its export control policies, resulting in severe damage to the supply chains of some companies in *Computer, Communication,* and *Other Electronic Equipment Manufacturing*. Therefore, the *Treat* value of this industry equals 1 in 2017 and after, and 0 otherwise. In April 2018, the US imposed an additional 25% tariff on Chinese chemicals, medicines, and rubber products. Therefore, the *Treat* values of these industries equal 1 in 2018 and after, and 0 otherwise.

We use two indicators to evaluate export competitiveness in the US, that is, industrial export intensity to the US.

The first is the industrial share of regional markets in China's global exports (*MS*). The industrial share of the US market (*MS_USA*)[3] can be derived from Eq. (3).

$$MS_{m,j,t} = \frac{X_{m,j,t}}{X\_world_t} \tag{3}$$

where *j* represents the corresponding two-digit industry under China's *Guidelines on Industry Classification of Listed Companies* (2012 revision) released by the China Securities Regulatory Commission; $X_{m,j,t}$ represents the export volume of China in industry *j* to country *m* in year *t*, and X_world_t the total export volume of China to the world in year *t*.[4] The larger the ratio, the more important the market of country *m* in industry *j* of China's export trade.

The second indicator is China's export comparative advantage in bilateral trade (*NTB*). To evaluate the level at which China dominates bilateral exports, we follow Buckley et al. (1988) and Ali (1992) to construct an industry-normalized trade balance (*NTB*) to evaluate China's industrial export intensities concerning the US market, as shown in Eq. (4). This reflects China's relative trade surplus with trade partners.

$$NTB_{m,j,t} = \frac{X_{m,j,t} - M_{m,j,t}}{X_{m,j,t} + M_{m,j,t}} \tag{4}$$

where $M_{m,j,t}$ represents the import volume of China's industry *j* from country *m* in year *t*. The higher the *NTB*, the greater the proportion of China's exports to country *m* in the total bilateral trade volume, meaning that the relative trade surplus of China against country *m* in industry *j* is greater and that China has greater export intensities in industry *j* in bilateral trade with country *m*.

We use corporate R&D intensity (*Innovation*) to measure corporate technological innovation in Eqs. (1) and (2). It is the ratio of R&D expenditures to total assets (He et al., 2016). In Eqs. (1) and (2), *ROA* denotes firm profitability.

The control variables include firm size (*Size*), leverage (*Lev*), firm age (*Age*), financial assets/sales ratio (*Inv*), non-cash assets (*NA*), Capex/PPE

[3] The trade data in this study are industrial aggregate data from the United Nations Comtrade database. There is no public trade data for individual Chinese firms to all countries in all industries.

[4] In the United Nations Comtrade database, global data are industry-agnostic or non-sectoral. Because of the huge work in matching each SITC six-digit product code in each year with the corresponding two-digit industry under the Industry Classification Guidelines for the Listed Companies of China, it is difficult to collect all export volumes of each two-digit industry to all countries or regions worldwide; thus, we use the total export volume of China to the world in year *t* as the denominator to calculate $MS_{m,j,t}$ in Eq. (3).

Table 2
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA	13,341	0.043	0.097	−7.700	0.482
MS_USA	13,341	0.996%	1.041%	0.000%	3.729%
MS_EU	13,341	1.116%	0.875%	0.000%	5.248%
MS_ASEAN	13,341	0.611%	0.936%	0.000%	2.129%
NTB_USA	13,341	0.365	0.585	−1.000	1.000
NTB_EU	13,341	0.214	0.555	−1.000	1.000
NTB_ASEAN	13,341	0.248	0.594	−1.000	0.965
Innovation	13,341	0.045	0.042	0.000	0.832
Size	13,341	21.918	1.214	18.390	28.624
Lev	13,341	0.388	0.203	0.007	5.681
Age	13,341	2.719	0.397	0.693	4.127
Inv	13,341	0.132	0.290	−0.000	9.427
NA	13,341	0.979	0.128	−1.204	1.745
Capex/PPE	13,341	1.633	3.448	1.000	340.098
CF	13,341	0.048	0.069	−0.466	0.520

(*Capex/PPE*), and cash flow ratio (*CF*). v_j controls for the industry effect, w_t controls for the year effect, and $\varepsilon_{i,j,t}$ is the residual term. Table 1 provides a detailed explanation of these variables.

Apart from the above basic regression models to testify Hypotheses 1 and 2, we also test the two mechanisms of technological innovation on export diversification implied by Hypothesis 2. We construct Eqs. (5)–(8) to verify the role of developing new markets and the role of optimizing the geographical composition of the export market niches induced by technological innovation in the export diversification process triggered by the trade war. We focus on analyzing the changes in Chinese firms' export profitability to the two major alternative trade partners, i.e., the EU and ASEAN, other than the US, and the role of R&D in the diversification process. The former mechanism, i.e., the ability induced by technological innovation to diversify exports to the developed economies, may be more pronounced in exports to the EU, whereas the latter mechanism, i.e., ability induced by technological innovation to gain comparative advantage over developing economies (export destination), can be validated in exports to ASEAN. Thus, Eqs. (5) and (6) are used to test Mechanism 1 and Eqs. (7) and (8) are used to verify Mechanism 2.

$$\begin{aligned}ROA_{i,j,t} &= \partial + \beta_1 MS\_EU_{j,t-1} + \beta_2 Treat_{j,t} + \beta_3 Innovation_{i,j,t-1}\\ &+\beta_4 MS\_EU_{j,t-1} \times Treat_{j,t} + \beta_5 MS\_EU_{j,t-1} \times Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+\beta_6 MS\_EU_{j,t-1} \times Innovation_{i,j,t-1} + \beta_7 Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+Controls_{i,j,t-1} + v_j + w_t + \varepsilon_{i,j,t}\end{aligned} \tag{5}$$

$$\begin{aligned}ROA_{i,j,t} &= \partial + \beta_1 NTB\_EU_{j,t-1} + \beta_2 Treat_{j,t} + \beta_3 Innovation_{i,j,t-1}\\ &+\beta_4 NTB\_EU_{j,t-1} \times Treat_{j,t} + \beta_5 NTB\_EU_{j,t-1} \times Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+\beta_6 NTB\_EU_{j,t-1} \times Innovation_{i,j,t-1} + \beta_7 Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+Controls_{i,j,t-1} + v_j + w_t + \varepsilon_{i,j,t}\end{aligned} \tag{6}$$

$$\begin{aligned}ROA_{i,j,t} &= \partial + \beta_1 MS\_ASEAN_{j,t-1} + \beta_2 Treat_{j,t} + \beta_3 Innovation_{i,j,t-1}\\ &+\beta_4 MS\_ASEAN_{j,t-1} \times Treat_{j,t} + \beta_5 MS\_ASEAN_{j,t-1} \times Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+\beta_6 MS\_ASEAN_{j,t-1} \times Innovation_{i,j,t-1} + \beta_7 Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+Controls_{i,j,t-1} + v_j + w_t + \varepsilon_{i,j,t}\end{aligned} \tag{7}$$

$$\begin{aligned}ROA_{i,j,t} &= \partial + \beta_1 NTB\_ASEAN_{j,t-1} + \beta_2 Treat_{j,t} + \beta_3 Innovation_{i,j,t-1}\\ &+\beta_4 NTB\_ASEAN_{j,t-1} \times Treat_{j,t} + \beta_5 NTB\_ASEAN_{j,t-1} \times Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+\beta_6 NTB\_ASEAN_{j,t-1} \times Innovation_{i,j,t-1} + \beta_7 Treat_{j,t} \times Innovation_{i,j,t-1}\\ &+Controls_{i,j,t-1} + v_j + w_t + \varepsilon_{i,j,t}\end{aligned} \tag{8}$$

where *MS_EU* and *MS_ASEAN* represent the industrial shares of the EU and ASEAN markets in China's total exports, respectively, and *NTB_EU* and *NTB_ASEAN* represent China's industrial export intensities concerning the EU and ASEAN markets, respectively. All these variables represent China's export competitiveness in different markets. Coefficients β_4 and β_5 in the two markets are the foci of this study.

3.2. Sample and descriptive statistics

This paper uses a large panel dataset comprising all the Chinese manufacturing firms listed in the A-share markets in Shanghai and Shenzhen in 2007–19. The annual reports of the sample firms show that more than 70% of them have export earnings. Additionally, their R&D investment intensity (R&D expenditures/total assets) is higher than the average level of all industries, providing a potent impetus to the national innovation-driven development strategy.[5] The sample starts in 2007 rather than earlier, as the accounting standards clarifying R&D investments were issued only in 2006 and implemented in 2007.

Firm-level data were obtained from the China Stock Market Accounting Research database. Industrial data such as *MS* and *NTB* are calculated using the United Nations Comtrade database. In calculating national import or export volumes in certain industries, the SITC six-digit product code for each year is unified as SITC Rev3 and further used to perform with the corresponding two-digit industry under China's *Guidelines on Industry Classification of Listed Companies* (2012 revision). The import or export volumes of the two-digit industrial categories are further summarized.

We screen and process the sample by eliminating[6] (1) firms that do not comply with accounting principles, including those with total assets less than current assets, total assets less than net fixed assets, or accumulated depreciation less than current depreciation, and (2) ST and *ST firms.[7] After data cleaning, we obtained 13,341 firm-year observations from 31 manufacturing industries.

Table 2 presents the descriptive statistics of the relevant variables in the sample. The mean *ROA* is 0.043, the standard deviation is 0.097, the maximum value is 0.482, and the minimum value is −7.700, indicating that firm profitability varies significantly. Regarding a certain regional market share in a certain industry in China's total global exports, the mean *MS_USA* accounts for 0.996%, while the corresponding mean in relation to ASEAN (*MS_ASEAN*) accounts for 0.611% and to the EU (*MS_EU*) 1.116%, indicating that during the sample period, China's average industrial exports to the EU market are the largest, whereas exports to the ASEAN market are relatively small. Regarding China's export comparative advantages in bilateral trade, the mean *NTB_USA* is 0.365, whereas the corresponding mean in relation to ASEAN (*NTB_ASEAN*) is 0.248 and that of the EU (*NTB_EU*) 0.214, indicating that during the sample period, the trade surplus of China against the US, ASEAN, and the EU are all large and that China's manufacturing is more competitive and dominant in relation to the US than to ASEAN and the EU as far as bilateral trade is concerned. The mean *Innovation* is 0.045, the standard deviation is 0.042, the minimum is close to 0, and the maximum is 0.832. This shows that the gap in R&D intensity among Chinese manufacturing firms is obvious, with a wide range of technological innovation variations among the sample firms.

Panel A of Table 3 shows the difference in firm export profitability before and after the trade war, grouped by the median of industrial export intensity. Regarding the high industrial export intensity to the US (High *MS_USA* and High *NTB_USA*), *ROA* decreased by 2.70 percentage points (*MS_USA*) and 2.50 percentage points (*NTB_USA*) after the trade war, respectively, which are significant at the 1% level. Similar to the US, regarding the high industrial export intensity to the EU (High *MS_EU* and High *NTB_EU*), *ROA* decreased by 2.60 percentage points and 2.30 percentage points after the trade war, respectively, which are significant

[5] We include data up until 2019 only, owing to the outbreak of COVID-19 in 2020.

[6] If firms do not report R&D expenditures, we consider their R&D expenditures equal to 0.

[7] When a listed firm in Chinese stock markets shows abnormal or wrong activity in its financial situation or other circumstance, the China Securities Regulatory Commission denotes it as an "ST" or "*ST" company to warn current and potential investors.

Table 3
Group comparison.

Panel A						
Variable	*Treat*=1	*Treat*=0	T-test	*Treat*=1	*Treat*=0	T-test
		High *MS_USA*			Low *MS_USA*	
ROA	0.016	0.043	−0.027***	0.047	0.038	0.009***
		High *NTB_USA*			Low *NTB_USA*	
ROA	0 0.016	0.041	−0.025***	0.0471	0.035	0.012***
		High *MS_EU*			Low *MS_EU*	
ROA	0.016	0.042	−0.026***	0.046	0.035	0.011***
		High *NTB_EU*			Low *NTB_EU*	
ROA	0 0.018	0.041	−0.023***	0.047	0.033	0.015***
		High *MS_ASEAN*			Low *MS_ASEAN*	
ROA	0.041	0.019	0.021***	0.051	0.041	0.010***
		High *NTB_ASEAN*			Low *NTB_ASEAN*	
ROA	0.044	0.028	0.017***	0.044	0.022	0.022***

Panel B						
Variable	*Treat*=1			*Treat*=0		
	High R&D	Low R&D	T-test	High R&D	Low R&D	T-test
ROA	0.027	0.022	0.005***	0.047	0.043	0.004***

Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 4
Export profitability in the US and R&D intensity under the trade war: *MS_USA* as export intensity.

Variables	DV = *ROA*		
	(1)	(2)	(3)
MS_USA	0.964***	0.751**	0.759**
	(3.440)	(2.558)	(2.566)
Treat		−1.950***	−2.100***
		(−5.844)	(−6.175)
MS_USA×Treat		−0.291**	−0.052**
		(−2.458)	(−2.319)
MS_USA×Treat×Innovation			0.494***
			(2.899)
MS_USA×Innovation			0.023**
			(2.188)
Innovation			0.207***
			(3.037)
Treat×Innovation			0.355*
			(1.834)
Size	0.533***	0.532***	0.532***
	(9.584)	(9.577)	(9.565)
Lev	−8.680***	−8.640***	−8.590***
	(−25.54)	(−25.39)	(−25.02)
Age	−0.610***	−0.610***	−0.597***
	(−4.233)	(−4.230)	(−4.132)
Inv	1.570***	1.580***	1.590***
	(8.147)	(8.186)	(8.239)
NA	−1.720***	−1.710***	−1.720***
	(−4.229)	(−4.187)	(−4.211)
Capex/PPE	−0.112***	−0.112***	−0.112***
	(−5.621)	(−5.610)	(−5.611)
CF	30.000***	30.000***	30.000***
	(38.67)	(38.65)	(38.67)
Constant	−1.210	−1.280	−1.280
	(−0.881)	(−0.929)	(−0.931)
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	13,341	13,341	13,341
R-squared	0.230	0.231	0.231
Adjusted R2	0.228	0.228	0.228

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 5
Export profitability in the US and R&D intensity under the trade war: *NTB_USA* as export intensity.

Variables	DV = *ROA*		
	(1)	(2)	(3)
NTB_USA	1.060***	1.190***	1.250***
	(2.902)	(3.226)	(3.329)
Treat		−1.980***	−1.890***
		(−6.006)	(−5.470)
NTB_USA×Treat		−0.737**	−0.492**
		(−2.538)	(−2.452)
NTB_USA×Treat×Innovation			0.446**
			(2.559)
NTB_USA×Innovation			0.427***
			(3.057)
Innovation			0.334**
			(2.527)
Treat×Innovation			0.457***
			(3.204)
Size	0.536***	0.534***	0.532***
	(9.650)	(9.600)	(9.559)
Lev	−8.680***	−8.640***	−8.580***
	(−25.54)	(−25.37)	(−24.93)
Age	−0.600***	−0.606***	−0.594***
	(−4.157)	(−4.204)	(−4.110)
Inv	1.560***	1.580***	1.590***
	(8.078)	(8.206)	(8.238)
NA	−1.720***	−1.710***	−1.700***
	(−4.222)	(−4.191)	(−4.179)
Capex/PPE	−0.105***	−0.105***	−0.105***
	(−5.264)	(−5.253)	(−5.272)
CF	30.000***	30.000***	30.000***
	(38.66)	(38.67)	(38.66)
Constant	−0.616	−0.600	−0.557
	(−0.442)	(−0.431)	(−0.399)
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	13,341	13,341	13,341
R-squared	0.230	0.231	0.231
Adjusted R2	0.228	0.228	0.228

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

at the 1% level. However, regarding the high industrial export intensity to ASEAN (High *MS_ASEAN* and High *NTB_ASEAN*), *ROA* increased by 2.10 percentage points and 1.70 percentage points after the trade war, respectively, which are significant at the 1% level. The simple statistics indicate that after the trade war, Chinese firm export profitability in the ASEAN market rose significantly. In contrast, the export profitability evidently declined in both the US and the EU markets, but the reduction in the US market was more pronounced than in the EU market. One preliminary observation is that after the trade war, Chinese export firms may have diverted more exports, particularly of the high-value products,

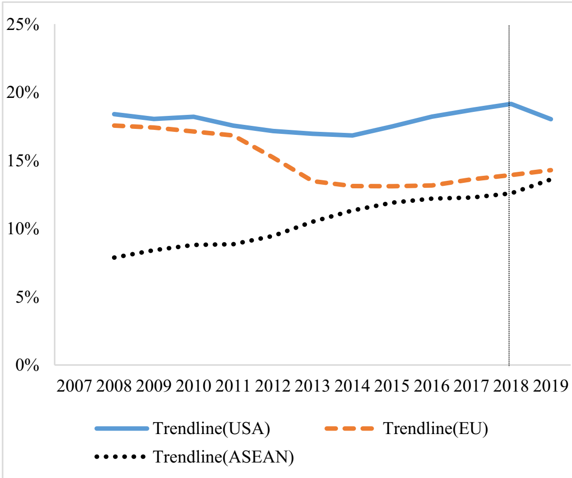

Fig. 1. Trends of shares of the US, the EU and ASEAN in China's export market, Notes: These are intensity trends of China's aggregate industrial exports (*MS*) to three major trading partners.

away from the US to ASEAN than to the EU to mitigate the negative shock triggered by the trade war.

Panel B of Table 3 shows the difference in firm export profitability before and after the trade war between different R&D levels, grouped by the industrial median of firm R&D intensity. Before the trade war, *ROA* in the high-R&D group was higher by 0.40 percentage points than those in the low-R&D group, with the difference being significant at the 1% level. After the trade war, *ROA* in the high-R&D group was higher by 0.50 percentage points than those in the low-R&D group, with the difference being significant at the 1% level. This shows that Chinese firms with higher R&D intensity performed better in export trade, especially after the trade war. This preliminary result suggests that high R&D intensity (technological innovation) is an important factor responsible for raising firm resilience to withstand the negative shock on export profitability caused by the trade war.

4. Basic regression results

Estimated results with respect to the relationship between firm profitability of export to the US and corporate R&D intensity before and after the trade war are presented in Tables 4 and 5. Table 4 presents the results based on Eq. (1), and Table 5 lists the results based on Eq. (2).

The results in column (1) of Table 4 show that firm export profitability is significantly and positively affected by exports to the US on average. As shown in column (1), the profitability is higher in industries with more trade surplus against the US. However, when considering the trade war shock, as shown in column (2), there is a significant change in the profitability of exports to the US. The estimated coefficient of *Treat* is −1.950 and significant at the 1% level, and the estimated coefficient of *MS_USA*×*Treat* is −0.291 and significant at the 5% level. Both estimated coefficients imply that Chinese firms with more trade surplus in the US suffer more disproportionately than those with less trade surplus, verifying Hypothesis 1 presented earlier of this paper.

Despite this, the estimated results in column (3) suggest that R&D intensity appears to have mitigated the negative impact induced by the trade war. The estimated coefficient on *MS_USA*×*Treat*×*Innovation* is 0.494 and significant at the 1% level. The *MS_USA*×*Innovation* coefficient is 0.023 and significant at the 5% level. Both estimated coefficients indicate that firms with higher R&D intensity are more able to withstand the negative shock of the trade war to export profitability than their lower R&D intensity counterparts, verifying Hypothesis 2 presented earlier of this paper.

The results in Table 5 are similar to those in Table 4. They suggest that firm profitability is significantly and positively affected by exports to the US on average. However, after the trade war, a significant reversal appears. As shown in column (2), the estimated coefficient of *Treat* is −1.980 and significant at the 1% level. The estimated coefficient of *NTB_USA*×*Treat* is −0.737 and significant at the 5% level. Both estimated coefficients imply that export profitability of Chinese firms in the US market suffered remarkably as a result of the trade war. However, as shown in column (3), R&D intensity appears to have mitigated the negative shock to export profitability triggered by the trade war. The *NTB_USA*×*Treat*×*Innovation* coefficient is 0.446 and significant at the 5% level. The *NTB_USA*×*Innovation* coefficient is 0.427 and significant at the 1% level.

5. Mechanism test

Hypothesis 2 implies that Chinese manufacturing firms with more intensive R&D were more able to diversify exports to alternative markets away from the US amid the trade war. The transmission mechanisms of technological innovation represented by R&D expenditures in mitigating the negative shock of the trade war to export profitability are reflected by two different abilities of the firms under concern: the ability to diversify exports from the US to other alternative markets (first mechanism) and the ability to optimize the composition of export markets (second mechanism).

Firstly, technological innovation empowers firms with the ability to divert exports through attracting new customers in different alternative markets. Secondly, technological innovation empowers firms with the ability to quickly adjust and optimize the composition of alternative export markets with different levels in the global value chains and industrial division. In the process of trade diversification induced by the trade war, Chinese firms may choose two important alternative markets, the EU and ASEAN, which have marked differences in technology and consumer preferences. As the technology and consumer preference in the EU are similar to those in the US, firms with high R&D intensity are more likely to choose the EU for export diversion due to the first mechanism or ability mentioned above. Firms may also choose ASEAN for export diversion due to the second mechanism or ability as advanced technologies enable export firms to enjoy greater comparative advantage in the ASEAN market.

From the perspective of market structure, there are significant differences between the EU and ASEAN markets. In terms of the economic development level and consumption structure, as developed economies, the US and the EU have stronger market demand for high-value products and diversified consumption, whereas most of the ten ASEAN countries are developing economies with lower consumption levels. The differences in economic development and consumption levels among the US, the EU, and ASEAN lead to different import demands. Therefore, the EU seems more appropriate as an alternative market for the US to Chinese export firms with higher R&D intensity. Consequently, the capability of attracting new customers in new markets brought about by technological innovation will play a more obvious role in promoting firm export profitability in the EU market.

However, from the perspective of the international industrial division, Chinese export firms with stronger R&D capabilities can enter a high value-added division more easily in trade diversification. The ASEAN countries mainly undertake low value-added assembly in the international division, which can be complementary to China; the EU is in a high value-added market niche in the international trade division, which is competitive with China in the target niche. Consequently, the ability to optimize the geographic composition of alternative export destinations brought about by firms' technological innovation will play a more significant role in promoting export profitability in the ASEAN market.

The purpose of this section is to identify the above-mentioned mechanisms of how R&D affects export diversification. It firstly analyzes the export diversification of the sample firms before and after the

Table 6
Export profitability in the EU and R&D under the trade war: *MS_EU* as export intensity.

Variable	DV =ROA		
	(1)	(2)	(3)
MS_EU	0.537***	0.506***	0.508***
	(2.908)	(2.740)	(2.749)
Treat		−2.080***	−2.300***
		(−6.243)	(−6.492)
MS_EU×Treat		−0.316***	−0.046**
		(−3.040)	(−2.299)
MS_EU×Treat×Innovation			0.606***
			(2.747)
MS_EU×Innovation			0.355***
			(2.855)
Innovation			0.046**
			(2.211)
Treat×Innovation			0.053**
			(2.484)
Size	0.534***	0.533***	0.533***
	(9.605)	(9.602)	(9.582)
Lev	−8.700***	−8.650***	−8.620***
	(−25.58)	(−25.42)	(−25.07)
Age	−0.608***	−0.609***	−0.598***
	(−4.213)	(−4.227)	(−4.136)
Inv	1.560***	1.570***	1.570***
	(8.079)	(8.130)	(8.163)
NA	−1.740***	−1.720***	−1.730***
	(−4.269)	(−4.218)	(−4.238)
Capex/PPE	−0.110***	−0.111***	−0.111***
	(−5.517)	(−5.578)	(−5.567)
CF	30.000***	30.000***	30.000***
	(38.66)	(38.64)	(38.65)
Constant	−1.150	−1.220	−1.200
	(−0.834)	(−0.887)	(−0.871)
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	13,341	13,341	13,341
R-squared	0.230	0.231	0.231
Adjusted R2	0.228	0.228	0.228

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 7
Export profitability in the EU and R&D under the trade war: *NTB_EU* as export intensity.

Variable	DV =ROA		
	(1)	(2)	(3)
NTB_EU	0.366*	0.332*	0.418**
	(1.845)	(1.849)	(2.055)
Treat		−2.400***	−2.310***
		(−7.377)	(−6.776)
NTB_EU×Treat		−0.188*	−0.311*
		(−1.688)	(−1.812)
NTB_EU×Treat×Innovation			1.260**
			(2.166)
NTB_EU×Innovation			0.372**
			(2.179)
Innovation			0.081**
			(2.469)
Treat×Innovation			0.328**
			(2.062)
Size	0.531***	0.531***	0.531***
	(9.551)	(9.543)	(9.542)
Lev	−8.680***	−8.670***	−8.620***
	(−25.51)	(−25.45)	(−25.04)
Age	−0.602***	−0.604***	−0.590***
	(−4.176)	(−4.185)	(−4.076)
Inv	1.560***	1.570***	1.580***
	(8.121)	(8.143)	(8.214)
NA	−1.710***	−1.710***	−1.700***
	(−4.204)	(−4.197)	(−4.167)
Capex/PPE	−0.107***	−0.107***	−0.109***
	(−5.369)	(−5.375)	(−5.456)
CF	30.100***	30.100***	30.100***
	(38.70)	(38.70)	(38.70)
Constant	−1.000	−1.050	−1.070
	(−0.737)	(−0.751)	(−0.761)
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	13,341	13,341	13,341
R-squared	0.230	0.230	0.230
Adjusted R2	0.227	0.227	0.227

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

trade war among China's three most important trade partners, the US, the EU and ASEAN, to ascertain the main target market for China's export shift. Then, the estimated results based on Eqs. (5)–(8) indicate whether the two mechanisms can be verified in export diversification amid the trade war as posited in Hypothesis 2.

5.1. China's exports to the US, the EU and ASEAN

Fig. 1 shows the intensity trends of China's aggregate industrial exports (*MS*) to three major trading partners, namely, the trends of shares of the US, the EU and ASEAN in China's export market. As the figure shows, China's export intensity to the US has remained at a high level since 2007, but with a small downward trend until 2014, followed by an upward trend until the trade war's widespread outbreak in 2018. After the start of the trade war, there was a significant decline in the intensity of China's exports to the US in 2019, reflecting the volatility and uncertainty of the Sino-US trade relationship.

In recent years, China's export intensity to ASEAN has shown a stable growth trend, and the export ratio increased significantly in 2019 following the Sino-US trade war, indicating that ASEAN's ranking as China's major trade partner was steadily improving. Moreover, in November 2020, the Regional Comprehensive Economic Partnership (RCEP) was signed to reduce further tariffs on ASEAN member states, lower trade barriers, and promote free trade in the region. As two important signatories to the RCEP, China and ASEAN are expected to develop closer trade relations. It implies that after the trade war, the ASEAN market is likely to become the more important export diversification option for China.

China's export intensity to the EU showed greater volatility. Although it increased after the trade war, its growth rate was less than that of ASEAN. Chinese enterprises seem to consider the EU less than ASEAN as a destination for export diversification for two reasons. On the one hand, the global economic downturn has suppressed international market demand, making the EU pay more attention to manufacturing and export. In addition, the EU's position in the international trade value chain is competitive with China's target market niches, thus increasing the difficulty for Chinese firms to expand their export to the EU. On the other hand, owing to the strong trade policy coordination between the EU and the US, they established a strategic bilateral trade tie after the trade war,[8] which, to some extent, also hindered China's export diversification to the EU.

5.2. Mechanism regression results

The test results are presented in Tables 6–9. Tables 6 and 7 present the results based on Eqs. (5) and (6). Tables 8 and 9 show the results based on Eqs. (7) and (8).

The results in Tables 6 and 7 show the relationship between firm profitability of export to the EU and R&D intensity. Comparing the

[8] In April 2018, the EU considered formulating a miniaturized and simplified Transatlantic Trade and Investment Partnership Agreement (TTIP). It aimed to meet the key requirements of the Trump administration: lowering tariffs on American cars and their parts and industrial machinery and equipment entering the EU. Source: http://www.cn.wsj.com/

Table 8
Export profitability in ASEAN and R&D under the trade war: *MS_ASEAN* as export intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
MS_ASEAN	−0.252	0.596***	0.637**
	(−0.532)	(3.152)	(2.206)
Treat		2.200***	2.440***
		(6.172)	(6.735)
MS_ASEAN×Treat		0.451**	0.420**
		(2.341)	(2.241)
MS_ASEAN×Treat×Innovation			1.330***
			(4.048)
MS_ASEAN×Innovation			0.194***
			(2.654)
Innovation			0.386***
			(2.645)
Treat×Innovation			0.011**
			(2.136)
Size	0.533***	0.533***	0.531***
	(9.583)	(9.590)	(9.553)
Lev	−8.690***	−8.670***	−8.590***
	(−25.53)	(−25.48)	(−25.00)
Age	−0.600***	−0.599***	−0.580***
	(−4.156)	(−4.151)	(−4.013)
Inv	1.560***	1.560***	1.580***
	(8.090)	(8.097)	(8.219)
NA	−1.720***	−1.710***	−1.720***
	(−4.219)	(−4.197)	(−4.213)
Capex/PPE	−0.105***	−0.105***	−0.105***
	(−5.267)	(−5.277)	(−5.256)
CF	30.000***	30.000***	30.000***
	(38.67)	(38.64)	(38.65)
Constant	−1.270	−1.290	−1.270
	(−0.921)	(−0.938)	(−0.921)
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	13,341	13,341	13,341
R-squared	0.230	0.230	0.231
Adjusted R2	0.228	0.228	0.228

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 9
Export profitability in ASEAN and R&D under the trade war: *NTB_ASEAN* as export intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
NTB_ASEAN	−0.157	0.145**	0.020***
	(−0.398)	(2.366)	(3.051)
Treat		2.250***	1.960***
		(7.069)	(5.848)
NTB_ASEAN×Treat		0.428**	0.781**
		(2.436)	(2.240)
NTB_ASEAN×Treat×Innovation			1.340**
			(1.999)
NTB_ASEAN×Innovation			1.010***
			(3.175)
Innovation			0.350**
			(1.996)
Treat×Innovation			0.748**
			(2.181)
Size	0.532***	0.531***	0.532***
	(9.569)	(9.555)	(9.556)
Lev	−8.680***	−8.690***	−8.630***
	(−25.52)	(−25.54)	(−25.09)
Age	−0.599***	−0.601***	−0.586***
	(−4.154)	(−4.164)	(−4.051)
Inv	1.560***	1.570***	1.600***
	(8.104)	(8.128)	(8.295)
NA	−1.720***	−1.720***	−1.710***
	(−4.211)	(−4.224)	(−4.197)
Capex/PPE	−0.106***	−0.106***	−0.106***
	(−5.310)	(−5.301)	(−5.318)
CF	30.100***	30.100***	30.100***
	(38.69)	(38.70)	(38.70)
Constant	−1.440	−1.470	−1.500
	(−1.006)	(−1.023)	(−1.045)
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	13,341	13,341	13,341
R-squared	0.230	0.230	0.231
Adjusted R2	0.227	0.227	0.227

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

situations before and after the trade war, there was a significant reversal in firm export profitability to the EU market, similar to the results of export to the US. Column (2) of Table 6 indicates that in the EU market, the estimated coefficient of *Treat* is −2.080 and the coefficient of *MS_EU×Treat* is −0.316, both of which are significant at the 1% level, implying that after the trade war, the profitability of firms in industries with more trade surplus against the EU declined. However, R&D intensity is found to have significantly mitigated the negative impact of the trade war on export profitability. The estimated *MS_EU×Treat×Innovation* coefficient is 0.606, and the estimated *MS_EU×Innovation* coefficient is 0.355, both of which are significant at the 1% level, indicating that even in the EU market, Chinese export firms with higher R&D intensity were more able to withstand the trade shock than their lower R&D intensity counterparts. The results in Table 7 are similar to those in Table 6.

The above results show that firm profitability of export to the EU declined after the trade war. This is because the strong trade policy coordination between the EU and the US may have hindered the effort of Chinese firms in diverting their exports to the EU. Nonetheless, technological innovation is found to have helped improving the resilience to the declining process because it enabled the Chinese firms to attract new customers through producing suitable products to meet the demand of EU consumers. This empirical finding verifies Mechanism 1 (the first ability) implied in Hypothesis 2.

The estimated results in Tables 8 and 9 show the relationship between firm profitability of export to ASEAN and R&D intensity. In Table 8, comparing the situations before and after the trade war, a significant change is found in firm profitability of export to ASEAN. In column (2) of Table 8, the estimated coefficient of *Treat* is 2.200 and significant at the 1% level. The estimated coefficient of *MS_ASEAN×Treat* is 0.451 and significant at the 5% level. Both estimated coefficients indicate that export profitability of Chinese firms in industries with more trade surplus against ASEAN surprisingly improved after the trade war. Moreover, the higher the firm R&D intensity, the more pronounced its effect on firm export profitability in the ASEAN market. This is demonstrated in the results shown in column (3), the estimated coefficient of *MS_ASEAN×Treat×Innovation* is 1.330 and that of *MS_ASEAN×Innovation* is 0.194, both of which are significant at the 1% level. The estimated results in Table 9 are similar to those in Table 8.

The above results show that firm profitability of export to ASEAN improved after the trade war. In particular, R&D intensity is found to have made an important contribution to firm export profitability, evidently verifying Mechanism 2 (the second ability induced by innovation) in Hypothesis 2. It is apparent that technological innovation enables export firms to quickly adjust and optimize the geographical composition of alternative export destinations in the global industrial division under the trade war.

Further analysis based on the estimated results in Tables 6–9 also indicate that the induced ability by technological innovation to quickly adjust and optimize the geographical composition of alternative export destinations is more pronounced than the induced ability by technological innovation of export firms to attract new customers in different alternative markets. On the one hand, the trade war reduced export profitability of Chinese firms in the EU (see column 2 in Tables 6 and 7) but increased the profitability of exports to ASEAN (see column 2 in Tables 8 and 9), indicating that some Chinese firms had successfully

Table 10
Heterogeneity test on firm export profitability in the US market by industries .

Variables	DV = *ROA*					
	Industries more adversely affected			Industries less adversely affected		
	(1)	(2)	(3)	(4)	(5)	(6)
MS_USA	0.758**	−0.447**	−0.459**	2.610***	2.540***	2.390***
	(2.327)	(−2.315)	(−2.337)	(3.643)	(3.492)	(3.214)
Treat		−1.120**	−1.450***		2.720	2.770
		(−2.291)	(−2.797)		(0.759)	(0.444)
MS_USA×*Treat*		−0.463***	−0.024**		0.218	0.141
		(−3.182)	(−2.114)		(0.559)	(0.256)
MS_USA×*Treat*×*Innovation*			0.726**			0.042**
			(2.345)			(2.215)
MS_USA×*Innovation*			0.809**			0.776*
			(2.493)			(1.749)
Innovation			0.149**			0.446**
			(2.433)			(2.315)
Treat×*Innovation*			0.577***			0.027**
			(2.874)			(2.418)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7680	7680	7680	5661	5661	5661
R-squared	0.173	0.174	0.175	0.315	0.315	0.315
Adjusted R2	0.171	0.171	0.171	0.310	0.310	0.310

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 11
Heterogeneity test on firm export profitability in the EU market by industries .

Variable	DV = *ROA*					
	Industries more adversely affected			Industries less adversely affected		
	(1)	(2)	(3)	(4)	(5)	(6)
MS_EU	0.384*	−0.348***	−0.352***	1.350***	1.350***	1.250**
	(1.792)	(−2.624)	(−2.637)	(2.647)	(2.634)	(2.403)
Treat		−1.210**	−1.560***		2.990***	2.860***
		(−2.466)	(−3.003)		(6.307)	(5.524)
MS_EU×*Treat*		−0.469***	−0.048**		0.273	0.554
		(−3.657)	(−2.260)		(0.656)	(0.893)
MS_EU×*Treat*×*Innovation*			0.733***			0.667
			(2.640)			(0.773)
MS_EU×*Innovation*			0.712**			0.372
			(2.091)			(0.578)
Innovation			0.038**			0.283
			(2.114)			(0.842)
Treat×*Innovation*			0.056**			0.505
			(2.413)			(1.141)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7680	7680	7680	5661	5661	5661
R-squared	0.172	0.174	0.175	0.314	0.314	0.314
Adjusted R2	0.171	0.171	0.171	0.309	0.309	0.309

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

diverted their exports to ASEAN, taking advantage of their technological capability in the geographic division of the globe industrial chain. On the other hand, the triple interaction coefficient of export competitiveness, the trade war, and firm R&D intensity in the ASEAN market (see column 3 in Tables 8 and 9) is much larger than that in the EU (see column 3 in Tables 6 and 7), indicating that technological innovation plays a greater role in promoting export profitability in the ASEAN market.

6. Further analyses

6.1. Heterogeneity test

The impact of the trade war on the Chinese firms in different industries varies significantly. In this sub-section, all the sample firms are divided into two groups: (1) firms in the industries which were more adversely affected by the trade war; (2) firms in the industries which were less adversely affected. $\triangle$*MS_USA* measures the change in the annual average *MS_USA* values before and after the trade war. Because *MS_USA* reflects the export intensity of Chinese firms to the US, its change reflects the impact of the trade war on their exports. Consequently, industries with $\triangle$*MS_USA* less than the median of this indicator are those more adversely affected; otherwise, the industries are less adversely affected.

The group regression results are presented in Table 10. There is a clear difference between the two groups as far as the negative impact of the trade war on export profitability is concerned. The results similar to those in Table 4 appear only in columns (1)–(3) of Table 10. In other words, only in the more adversely affected industries, firms suffered a significant decline in export profitability under the trade war, but even

Table 12
Heterogeneity test on firm export profitability in the ASEAN market by industries .

Variable	DV = *ROA*					
	Industries more adversely affected			Industries less adversely affected		
	(1)	(2)	(3)	(4)	(5)	(6)
MS_ASEAN	−0.429	0.130**	0.050***	0.955	0.913	1.360
	(−0.675)	(2.190)	(3.715)	(1.011)	(0.960)	(1.413)
Treat		1.180**	1.960***		3.180***	3.520***
		(2.139)	(3.317)		(6.470)	(6.698)
MS_ASEAN×*Treat*		0.822**	0.607**		0.294	1.300
		(2.223)	(2.236)		(0.422)	(1.472)
MS_ASEAN×*Treat*×*Innovation*			2.910***			0.019**
			(3.736)			(2.256)
MS_ASEAN×*Innovation*			1.980**			0.580*
			(2.339)			(1.822)
Innovation			0.020**			0.691*
			(2.467)			(1.881)
Treat×*Innovation*			0.249**			1.780**
			(2.274)			(2.313)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7680	7680	7680	5661	5661	5661
R-squared	0.172	0.173	0.175	0.313	0.313	0.315
Adjusted R2	0.171	0.171	0.171	0.309	0.309	0.309

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix 1.1
Heterogeneity test on firm export profitability in the US market by industries.

Variable	DV = *ROA*					
	Industries more adversely affected			Industries less adversely affected		
	(1)	(2)	(3)	(4)	(5)	(6)
NTB_USA	0.256	−0.409***	−0.285***	1.640***	1.540***	1.570***
	(0.372)	(−2.595)	(−3.412)	(3.804)	(3.515)	(3.558)
Treat		−0.265**	−0.345***		2.690***	2.630***
		(−2.510)	(−2.633)		(6.075)	(5.694)
NTB_USA×*Treat*		−3.000***	−2.350***		0.515	0.360
		(−5.800)	(−3.953)		(1.339)	(0.821)
NTB_USA×*Treat*×*Innovation*			1.690**			0.750*
			(2.348)			(1.818)
NTB_USA×*Innovation*			0.232**			0.261*
			(2.286)			(1.778)
Innovation			0.668*			0.960**
			(1.697)			(2.379)
Treat×*Innovation*			0.949***			0.321**
			(3.518)			(2.285)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7680	7680	7680	5661	5661	5661
R-squared	0.172	0.176	0.177	0.315	0.315	0.315
Adjusted R2	0.173	0.173	0.173	0.310	0.310	0.310

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

for these firms, technological innovation is still found to have alleviated the adverse effect. This finding is supported by the estimated results in columns (2) and (3), where the estimated coefficient of *Treat* is −1.120 and significant at the 5% level, the estimated coefficient of *MS_USA*×*Treat* is −0.463 and significant at the 1% level (see column 2), and the estimated coefficient of *MS_USA*×*Treat*×*Innovation* is 0.726 and significant at the 5% level (see column 3). This finding reinforces the empirical results presented in the previous section, further verifying Hypotheses 1 and 2 presented in this paper. From the estimated results in Table 10, it is interesting to find that for the Chinese firms in industries less adversely affected by the trade war, their export profitability to the US does not appear to have been significantly influenced. In addition, for the same group of firms, their R&D intensity is also found to have played a less potent mitigating role in reducing the negative impact of the trade war on export profitability compared to firms in the more adversely affected industries.

Group regression results of firm export to the EU are presented in Table 11 based on Eq. (5) in the same grouped sub-samples. The results similar to those in Table 6 appear only in columns (1)–(3) of Table 11. In other words, only firms in the more adversely affected industries are found to suffer a significant decline in their export profitability in the EU under the trade war. R&D intensity is also found to have played a mitigating role in reducing the negative impact of the trade war on firm export profitability. These findings are supported by the estimated results in Table 11, where the estimated coefficient of *Treat* is −1.210 and significant at the 5% level, the estimated coefficient of *MS_EU*×*Treat* is −0.469 and significant at the 1% level (see column 2), and the estimated coefficient of *MS_EU*×*Treat*×*Innovation* is 0.733 and significant at the 1% level (see column 3). As for firms in the less adversely influenced industries, their export profitability in the EU does not appear to have

Appendix 1.2
Heterogeneity test on firm export profitability in the EU market by industries.

Variable	DV = *ROA*					
	Industries more adversely affected			Industries less adversely affected		
	(1)	(2)	(3)	(4)	(5)	(6)
NTB_EU	1.530**	−1.340*	−1.440*	0.168**	0.265**	0.319*
	(2.023)	(−1.767)	(−1.879)	(2.369)	(2.577)	(1.688)
Treat		−1.180**	−1.370***		2.990***	3.000***
		(−2.367)	(−2.593)		(6.600)	(6.349)
NTB_EU×Treat		−2.160***	−0.919**		0.779**	0.667
		(−4.017)	(−2.377)		(2.093)	(1.506)
NTB_EU×Treat×Innovation			2.970**			0.216
			(2.556)			(0.263)
NTB_EU×Innovation			0.482*			0.061
			(1.752)			(0.143)
Innovation			0.232***			0.085
			(2.696)			(0.360)
Treat×Innovation			0.095**			0.453
			(2.164)			(0.965)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7680	7680	7680	5661	5661	5661
R-squared	0.172	0.174	0.176	0.313	0.314	0.314
Adjusted R2	0.172	0.172	0.172	0.309	0.309	0.309

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix 1.3
Heterogeneity test on firm export profitability in the ASEAN market by industries.

Variable	DV = *ROA*					
	Industries more adversely affected			Industries less adversely affected		
	(1)	(2)	(3)	(4)	(5)	(6)
NTB_ASEAN	−0.440	0.471*	0.130**	0.038	0.017	0.010
	(−0.772)	(1.822)	(2.222)	(0.719)	(0.318)	(0.186)
Treat		1.880***	1.470***		2.560***	2.610***
		(4.207)	(3.109)		(5.579)	(5.542)
NTB_ASEAN×Treat		0.243**	0.403***		1.030**	0.943**
		(2.323)	(2.740)		(2.490)	(2.090)
NTB_ASEANA×Treat×Innovation			1.780***			0.883***
			(3.614)			(2.673)
NTB_ASEAN×Innovation			1.180***			0.550***
			(3.001)			(2.677)
Innovation			0.294**			0.041*
			(2.406)			(1.894)
Treat×Innovation			1.190**			0.083**
			(2.223)			(2.120)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7680	7680	7680	5661	5661	5661
R-squared	0.172	0.172	0.174	0.313	0.314	0.314
Adjusted R2	0.170	0.170	0.170	0.309	0.309	0.309

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

been significantly affected by the trade war and the corresponding mitigating effect of R&D is insignificant. The results in Table 11 are not dissimilar to those in Table 10, implying that the impact of the trade war on export profitability of Chinese firms is similar irrespective of their export destinations in the US or in the EU.

The same test on firm profitability of exports to ASEAN based on the same grouped sub-samples is also conducted and the estimated results based on Eq. (7) are presented in Table 12. The results similar to those in Table 8 appear only in columns (1)–(3) of Table 12. In other words, only firms in the industries more adversely affected by the trade war are found to significantly improve their export profitability in ASEAN. R&D is also found to have played an amplifying role in raising firm export profitability in ASEAN under the trade war. These findings are supported by the estimated results in Table 12, where the estimated coefficient of *MS_ASEAN×Treat* is 0.822 and significant at the 5% level (see column 2), and the estimated coefficient of *MS_ASEAN×Treat×Innovation* is 2.910 and significant at the 1% level (see column 3). In contrast, firms in the industries less adversely influenced are found to have been insignificantly affected by the trade war for their export profitability in ASEAN. The corresponding amplifying effect of R&D is also found to have been less potent for this group of firms than for the other group of firms.

We also perform group regressions by firm groups classified by the sample median of $\triangle$*NTB_USA* (rather than the median of $\triangle$*MS_USA*) which measures the change in the annual average values of *NTB_USA* before and after the trade war. Firms in the industries whose $\triangle$*NTB_USA* value is less than the median are regarded as more adversely affected; otherwise, they are less adversely affected. The regression results by groups are listed in the Appendix Tables 1.1, 1.2, 1.3, and they are not dissimilar to those presented in this section where the sample firms are

Appendix 2.1
Shortening the sample interval: *MS_USA* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
MS_USA	1.680***	1.150**	1.010*
	(3.413)	(2.117)	(1.828)
Treat		−1.270***	−1.420***
		(−4.076)	(−4.155)
MS_USA×Treat		−0.348**	−0.080***
		(−2.351)	(−3.367)
MS_USA×Treat×Innovation			0.427**
			(2.450)
MS_USA×Innovation			0.276**
			(2.457)
Innovation			0.304***
			(2.981)
Treat×Innovation			0.326*
			(1.658)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	7906	7906	7906
R-squared	0.216	0.216	0.218
Adjusted R2	0.213	0.213	0.213

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix 2.2
Shortening the sample interval: *MS_EU* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
MS_EU	1.270***	0.760*	0.628*
	(2.983)	(1.776)	(1.876)
Treat		−1.360***	−1.500***
		(−4.449)	(−4.467)
MS_EU×Treat		−0.309**	−0.058**
		(−2.212)	(−2.288)
MS_EU×Treat×Innovation			0.402**
			(2.478)
MS_EU×Innovation			0.296*
			(1.658)
Innovation			0.255*
			(1.833)
Treat×Innovation			0.224**
			(2.260)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	7906	7906	7906
R-squared	0.216	0.216	0.217
Adjusted R2	0.212	0.212	0.212

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix 2.3
Shortening the sample interval: *MS_ASEAN* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
MS_ASEAN	−0.491	0.240**	0.540**
	(−0.571)	(2.256)	(2.563)
Treat		1.470***	1.880***
		(4.329)	(4.938)
MS_ASEAN×Treat		0.628*	0.326*
		(1.920)	(1.739)
Innovation			0.297*
			(1.797)
MS_ASEAN×Treat×Innovation			1.860***
			(2.845)
MS_ASEAN×Innovation			0.972*
			(1.675)
Treat×Innovation			0.394*
			(1.898)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	7906	7906	7906
R-squared	0.215	0.215	0.217
Adjusted R2	0.212	0.212	0.212

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix 2.4
Shortening the sample interval: *NTB_USA* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
NTB_USA	0.877***	0.703*	0.640*
	(3.082)	(1.864)	(1.784)
Treat		−1.520***	−1.380***
		(−5.079)	(−4.246)
NTB_USA×Treat		−0.822**	−0.691*
		(−2.380)	(−1.704)
NTB_USA×Treat×Innovation			0.132**
			(2.167)
NTB_USA×Innovation			0.429*
			(1.918)
Innovation			0.273*
			(1.938)
Treat×Innovation			0.658**
			(2.276)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	7906	7906	7906
R-squared	0.215	0.215	0.216
Adjusted R2	0.211	0.211	0.211

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

grouped based on the median of $\triangle$*MS_USA*.

6.2. Robustness tests

(1) Shortening the sample interval

The Sino-US trade war started in 2017, and the sample period of this study was 2007–19. Considering that time asymmetry before and after the trade war may potentially lead to inconsistent results, this subsection redefines the data sample by equalizing the time lengths before and after the trade war so that the new sample period becomes 2014–19. Various corresponding regression results in line with those presented in the previous sections are listed in the Appendix Tables 2.1, 2.2, 2.3, 2.4, 2.5, 2.6. The new regression results and their statistical inferences are not dissimilar to those presented in Tables 4–9, though. The robustness tests affirm that the basic regression results and the mechanism test results based on the entire sample period are consistent and robust, reinforcing Hypotheses 1 and 2 presented in this paper.

(2) Alternative statistical standard of trade volumes

The two systems of commodity classification standards commonly used in international trade statistics are the Standard International Trade Classification (SITC), which we employed in this study, and the International Convention for Harmonized Commodity Description and Coding System (HS). Considering the difference in the statistical caliber of the two standards, we use the HS code to recompute the variables of *MS* and *NTB* in this section. Specifically, to calculate national import or export volumes in certain industries, we use the HS six-digit product code to correspond with the two-digit industry code of China's industry and finally sum the import or export volumes of the two-digit industrial categories. Eqs. (1)–(8) are then re-estimated, and the regression results are presented in Appendix Tables 3.1 and 3.2. The estimates are consistent with our main findings, indicating that the results of this study are not affected by the statistical criteria of the trade data.

Appendix 2.5
Shortening the sample interval: *NTB_EU* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
NTB_EU	2.780***	2.750***	2.790***
	(3.116)	(3.083)	(3.109)
Treat		−1.780***	−1.660***
		(−6.516)	(−5.605)
NTB_EU×*Treat*		−0.468**	−0.754**
		(−2.444)	(−2.019)
NTB_EU×*Treat*×*Innovation*			1.140*
			(1.678)
NTB_EU×*Innovation*			0.254*
			(1.694)
Innovation			0.817**
			(2.035)
Treat×*Innovation*			0.082**
			(2.191)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	7906	7906	7906
R-squared	0.216	0.216	0.217
Adjusted R2	0.212	0.212	0.212

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix 2.6
Shortening the sample interval: *NTB_ASEAN* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
NTB_ASEAN	0.492	0.506*	0.721*
	(0.623)	(1.641)	(1.906)
Treat		1.750***	1.360***
		(6.274)	(4.398)
NTB_ASEAN×*Treat*		0.534**	1.110***
		(2.499)	(2.646)
NTB_ASEAN×*Treat*×*Innovation*			1.970**
			(2.505)
NTB_ASEAN×*Innovation*			1.080***
			(2.875)
Innovation			0.290**
			(2.136)
Treat×*Innovation*			0.863*
			(1.740)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	7906	7906	7906
R-squared	0.215	0.215	0.216
Adjusted R2	0.211	0.211	0.211

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix 3.1
Alternative statistical standard of trade volumes: *MS* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
MS_USA×*Treat*	−0.014***		
	(−5.788)		
MS_USA×*Treat*×*Innovation*	0.305***		
	(3.867)		
MS_USA×*Innovation*	−0.025		
	(−0.608)		
MS_USA	0.011**		
	(2.148)		
MS_EU×*Treat*		−0.023***	
		(−5.897)	
MS_EU×*Treat*×*Innovation*		0.451***	
		(3.667)	
MS_EU×*Innovation*		0.000	
		(0.004)	
MS_EU		0.008*	
		(1.755)	
MS_ASEAN×*Treat*			0.023***
			(3.662)
MS_ASEAN×*Treat*×*Innovation*			0.469**
			(2.354)
MS_ASEAN×*Innovation*			0.031
			(0.249)
MS_ASEAN			0.012
			(1.142)
Treat	−0.025***	−0.025***	0.027***
	(−3.632)	(−3.419)	(3.608)
Innovation	0.636***	0.606***	0.624***
	(8.330)	(7.568)	(6.612)
Treat×*Innovation*	0.229	0.204	0.161
	(1.598)	(1.345)	(0.969)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	10,379	10,379	10,379
R-squared	0.252	0.252	0.250
Adjusted R2	0.248	0.248	0.246

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

7. Conclusions and discussion

The key research findings and conclusions are summarized below.

The trade war has evidently reduced the profitability of firms with intensive export to the US, but the negative impact is mitigated by R&D activities. This is because R&D enables firms to produce high-value and competitive products, empowering them to easily attract new customers in alternative markets where the technology level and consumer preference (such as the EU) are similar to those in the US. The second ability empowered by technological innovation to the export firms is that they can quickly adjust and optimize the geographical composition of alternative export destinations where they may enjoy more competitiveness and global industrial division advantages (such as in ASEAN). The empirical results also reveal that the second ability of Chinese firms to divert exports to ASEAN empowered by R&D activities is more pronounced than the ability induced by technological innovation to divert exports of high-value products to the EU.

Based on trade competition, this study provides new evidence on enhancing the flexibility of economic development through technological innovation in developing countries. It enriches trade theory and literature in the relevant fields. The current international trade environment is deteriorating, protectionism intensifies, and the global industrial value chain is undergoing fragmentation and reconstruction. However, the pandemic, climate change, digital security, and artificial intelligence technology have brought about risks and challenges that require global cooperation.

Our results have important reference values for national trade development and corporate ability to face future trade frictions or other unexpected external shocks. On the one hand, firms should reinforce their investment in technological innovation through R&D, and continuously deepen product differentiation to cultivate high-value goods with strong international competitiveness, raising their resilience to withstand any unexpected external shock such as the trade war. On the other hand, countries should transcend their differences and focus on cooperation, actively participate in the negotiation and construction of global and regional economic integration, establish good bilateral and multilateral trade relations, and strengthen comprehensive exchanges and collaboration with each other.

Specifically, the results of this study have important policy implications for international trade in China especially in core technology manufacturing areas where trade friction is growing. It can be argued that while the US legal trade framework is undergoing transformation, the severity of the trade war has not been alleviated by the new US administration under President Joe Biden. The focus of the trade war

Appendix 3.2
Alternative statistical standard of trade volumes: *NTB* as exports intensity.

Variable	DV = *ROA*		
	(1)	(2)	(3)
NTB_USA×Treat	−0.021***		
	(−3.897)		
NTB_USA×Treat×Innovation	0.439**		
	(1.961)		
NTB_USA×Innovation	0.006		
	(0.047)		
NTB_USA	0.011**		
	(2.129)		
NTB_EU×Treat		−0.016***	
		(−2.990)	
NTB_EU×Treat×Innovation		0.399**	
		(1.968)	
NTB_EU×Innovation		0.071	
		(0.586)	
NTB_EU		0.007	
		(1.050)	
NTB_ASEAN×Treat			0.015***
			(2.799)
NTB_ASEAN×Treat×Innovation			0.420**
			(2.033)
NTB_ASEAN×Innovation			0.189*
			(1.718)
NTB_ASEAN			0.009*
			(1.711)
Treat	−0.030***	−0.038***	0.033***
	(−4.441)	(−5.541)	(4.785)
Innovation	0.645***	0.644***	0.710***
	(8.586)	(10.659)	(11.086)
Treat×Innovation	0.305**	0.407***	0.287**
	(2.283)	(3.759)	(2.553)
Controls	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	10,379	10,379	10,379
R-squared	0.250	0.250	0.250
Adjusted R2	0.246	0.246	0.245

Notes: T-statistics are in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

shifted to more high-tech fields. Although the USTR issued a statement announcing a renewed exemption from tariffs on 352 imports from China on March 23, 2022, and this exclusion from tariffs was further extended for nine months in December 2022, the US continues to be tough on China in the core technology manufacturing areas of trade competition, especially chip manufacturing. Compared to chip manufacturing, some of the aforementioned 352 categories have less R&D investment and intermediate positioning in the value chain. On August 9, 2022, Biden signed the Chip and Science Act of 2022, which provides huge subsidies to US domestic chip companies and restricts their trade and investment with China. On October 7, 2022, the US Bureau of Industry and Security imposed strict limitations and broader control on the export and exchange of chip technology, from final products to the entire production chain. In this regard, the current US administration has exceeded the intensity of the trade confrontation compared with the previous one. It is far more challenging and significant for Chinese firms to sustain their trade competitiveness through R&D investment strategies.

It also sheds light for the US to re-evaluate the effectiveness of its future trade policies with China. In such a situation, we must recognize that bilateral trade between China and the US cannot be entirely played as a zero-sum economic or political game. Although it has evidently harmed Chinese export firms, it may have harmed the US economy and consumers even more seriously. The strong recovery of bilateral and multilateral trade between the two countries and other major economies of the world in 2020–21 amid the Covid-19 pandemic has demonstrated that a trade-decoupling intention against China, as the world's largest export economy, is unrealistic. Instead, mutual trust and cooperation may still be an inevitable trend, irrespective of any political intervention by any trade economies, small or large, weak or strong. Therefore, equal dialog, consultation, and negotiation can mitigate global supply chain fragility and are conducive to global economic development.

It is of particular concern that the impact of the Sino-US trade war has spread to other countries along the global value chain, making the role of the EU and ASEAN an issue that requires long-term attention. Chinese ICT firms with high R&D propensity will find it increasingly difficult to substitute US technologies and final demand with European ones, given the current unity among allies. However, the US Chip and Science Act and the Inflation Reduction Act have caused dissatisfaction in some EU countries, which may present alternative market opportunities for Chinese firms. Meanwhile, ASEAN's role as a market for Chinese firms to diversify their exports seems increasingly important. China will vigorously promote the "Belt and Road," develop closer trade relations with ASEAN countries, and alter its trade patterns through cooperation with ASEAN countries to seek further breakthroughs.

CRediT authorship contribution statement

Duan Liu: Conceptualization, Formal analysis, Writing – original draft & review, Secure Funding, Supervision. **Qiuhong Wang:** Formal analysis, Writing – original draft. **Aidi Wang: Dat**a Curation, Methodology, Formal analysis, Writing – original draft. **Shujie Yao:** Conceptualization, Methodology, Writing – review & editing, Secure Funding. All authors were involved in writing the paper and we declare that there is no conflict of interest.

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Declaration of Competing Interest

None.

Data availability

Data will be made available on request.

Appendix

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