Export Competition and Innovation*

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March 19, 2024

Abstract

How does the rise of China affect innovation of firms in other countries through *export competition*, which means competition in third markets? A multi-country model developed in this paper predicts that only high-productivity firms increase innovation facing tougher competition with China. The model also suggests a possibility that innovation could be more responsive to export competition than to import competition. South Korean patent data confirm these predictions using a novel firm-level measure of export competition. Notably, export competition in markets where Korea outpaces China and in countries with higher income plays a more important role in Korean firm's innovation.

Keywords: Export competition, Innovation, Quality differentiation, Firm heterogeneity, International trade.

JEL Codes: F12, F14, O31, O53

*I am grateful for guidance and support from my advisors: Robert Feenstra, Katheryn Russ, and Ina Simonovska. I would like to thank Munseob Lee, Peter Morrow, Gianluca Orefice, Deborah Swenson, Takuya Ura, Jaerim Choi, Kyle Handley, Jaedo Choi, Shu Shen, Emile Marin, Kalina Manova, Jevan Churniwchan, Matilde Bombardini, Theresa Greaney, Liang Wang, Andres Carvajal, Giuseppe Ippedico, Sean Kim, Jae Wook Jung, Seunghoon Na, Jaebeom Kim, and participants of seminars at the 29th FREIT-EIIT, the 97th WEAI, the 17th APTS, the 10th WCTW, the University of Hawai'i at Mānoa, National Taiwan University, Syracuse University, Texas A&M, Georgia Tech, and UC Davis for helpful comments. I am especially grateful to UC Davis Shields library and the Department of Economics for supporting data acquisition.

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1 Introduction

As Chinese exports have grown exponentially after its accession to the World Trade Organization (WTO) in 2001, firms in other countries experience fierce competition with Chinese competitors not only in their domestic markets but also in their export markets. What are the consequences of rising competition with China in third countries (henceforth export competition)? Unlike the actively explored import competition (Autor et al., 2013; Acemoglu et al., 2016; Pierce and Schott, 2016; Autor et al., 2020), little is known about the impact of export competition with Chinese firms. This paper focuses on the innovation consequences of this under-explored export competition with China both theoretically and empirically.

Exploring the export competition with China is important for at least three reasons. First, Chinese exports have increased worldwide by a large magnitude, which suggests that export competition with Chinese firms should be prevalent.[1] Second, since innovation and exports are skewed toward high-productivity firms, and since export competition is likely to have disproportionate impact on exporting firms, export competition is expected to be influential to innovating firms' decision making.[2] Finally, as optimal strategies for firms to address increasing competition may vary across markets, the impact of export competition could differ from that of import competition. However, in spite of this importance, export competition has remained surprisingly understudied. To my knowledge, this is the first attempt to study the innovation consequences of export competition with China.

From the perspective of theory, I develop a multi-country model with productivity-enhancing innovation incorporating quality preferences into a Melitz (2003) style heterogeneous firm model, where firms choose the quality of their products based on their productivity. The model shows that firms with higher productivity endogenously engage in more innovation because only high-productivity firms can afford the cost of innovation. More

[1] The Chinese share of manufacturing exports increased from 4.32% in 2001 to 10.32% in 2007. Imports from China increased in 200 out of 220 countries, growing 315% on average during the same period (*Source: Base pour l'Analyse du Commerce International (BACI)*).

[2] In the sample used in this study, exporters account for 72.3% of patent applications between 2001 and 2007 in South Korea.

importantly, it is also shown that the rise of China, modeled as an exogenous increase in the number of Chinese firms, has a heterogeneous impact on innovation in that only high-productivity firms increases innovation in response to tougher competition with China through the following mechanisms: *scale effect* and *accumulation effect*.

To begin with the scale effect, as quality-adjusted prices fall due to the surging imports from China, the utility of consumers rises in importing countries. As a result of this utility increase, consumers regard product quality more importantly similar to Feenstra and Romalis (2014), which incentivizes firms to produce products with better quality. Therefore, the benefits of innovation increase since innovation makes it cheaper to produce higher-quality products. However, only high-productivity firms engage in more innovation because low-productivity firms cannot afford the cost of innovation facing the downward pressure on profits caused by more intense competition with China. Indeed, low-productivity firms may even decrease innovation facing tougher competition with China.

If domestic market is the only market considered, this scale effect is the only channel through which heterogeneous innovation responses arise in the model. However, since imports from China increase all over the world, exporting firms are exposed to competition with China in their export markets on top of the domestic market, each of which motivates exporting firms to innovate. By incorporating this extra innovation incentives arising from multiple export markets explicitly, the model shows that high-productivity firms, which export to more markets and therefore face competition with China in more markets, increase innovation further to escape from competition with China in their export markets. As a result, this accumulation effect strengthens the heterogeneous responses in innovation occurring from the scale effect.

In addition to the heterogeneity across firms, the theoretical model suggests a potential heterogeneity across markets where competition with China intensifies. More specifically, in the global economy, firms compete in diverse markets, where each market varies in importance and potential for escaping from competition through innovation. This implies that the most effective strategies to handle competition may differ across markets even for the same firm. Therefore, it is possible that competition with China in certain countries may have systematically stronger influence on firms' innovation decisions. For instance, competition in domestic market could be more important than in foreign markets, or competition in richer markets could be more important than in other markets. The theoretical model incorporates this possibility and suggests that firm's innovation incentives can be decomposed into the sum of contributions from each market, while the relative importance of each market is left as an empirical question.

In sum, the theoretical model predicts heterogeneous responses across firms in that only high-productivity firms increase innovation facing tougher competition with China. However, there is ambiguity in the overall impact, as low-productivity firms may decrease innovation at the same time. Additionally, the relative importance of competition in each market also remains ambiguous. Based on this guidance, the empirical analysis explores three dimensions. First, the overall impact and the relative importance of import competition and export competition on innovation is investigated. Second, the theoretical prediction of the heterogeneous responses across firms with different productivity is examined. Third, the relative importance of competition in countries with certain characteristics are analyzed to explore potential factors that influence firms' innovation decision, and thereby the relationship between competition and innovation.

In practice, South Korean firm-level data are employed by matching a universe of Korean patent data with a firm-level financial dataset KIS-VALUE because South Korea has several advantages in exploring these questions. First, as a small open economy relying heavily on export markets,[3] competition in export markets is expected to have a sizable impact on South Koran firms. Second, the technology gap between South Korea and China is narrower than the gap between China and developed countries, which implies that the rise of China

[3]Between 2001 and 2007, South Korea is the 14th largest exporting country (*source:* World Integrated Trade Solution), and its average exports to GDP ratio is as high as 34% (*source:* Bank of Korea).

should be an effective pressure on Korean firms.[4] Third, South Korean firms actively engage in innovation, which enables a large-scale firm-level analysis.[5]

Specifically, a novel firm-level measure of export competition is developed in this paper considering all possible export markets, in line with the theoretical model, in two steps. First, for each industry, using the growth in the Chinese share of imports as a proxy for rising competition with China in each export destination, a weighted sum of this proxy is computed using the importance of each market to Korean exports as a weight. This captures an industry-level export competition with China. Second, each firm's reliance on export markets, or the exports-to-sales ratio, is multiplied to this industry-level export competition measure to capture the effective exposure to this industry-level export competition at the firm-level. A firm-level import competition measure is similarly computed using Chinese share of imports in Korea and each firm's reliance on the domestic market.

Equipped with these measures, the impact of export competition and import competition on South Korean firms' innovation is investigated using the two-stage least squares (2SLS) strategy. In order to mitigate potential endogeneity concern related to import competition, the Chinese share of imports in Korea is instrumented by the Chinese share of imports in other countries following the literature (Autor et al., 2013). The measure of export competition is considered exogenous by construction and not instrumented since the variation of this measure only arises from changes in China or in export markets that are exogenous to Korean firms' decision.

For a further analysis on the heterogeneity by export destinations, the (overall) export competition measure is decomposed into the sum of export competition in group of countries with similar characteristics as the model suggests. Specifically, each export market (country-industry) is categorized as where Korean firms are leaders or laggards relative to Chinese competitors before China joined the WTO, and whether export competition in markets where

[4] di Giovanni et al. (2014) estimate that South Korea is the tenth most technologically similar country to China. Among the top 10 countries, South Korea is the largest exporter.

[5] The number of patent applications in South Korea between 2001 and 2007 is 969,093. Only Japan, the United States, and China led Korea during this period (*source:* World Intellectual Property Organization).

Korea leads has different impact on Korean firms' innovation decision from competition in markets where Korea lags. By doing so, this exercise extends Aghion et al. (2005) and Aghion et al. (2009) who emphasize that competition spurs innovation only for leaders or leading sectors by highlighting how the same firm responds differently to rising competition in markets where they lead and where they lag.

Similarly, the heterogeneity across export destinations is investigated by grouping countries based on their income, size, and distance from South Korea motivated by the quality upgrading motivation of innovation incorporated in the model and the literature on the relationship between product quality and export destination characteristics (Manova and Zhang, 2012; Brambilla et al., 2012; Brambilla and Porto, 2016; Bastos et al., 2018), which highlight that not export per se but where to export matters in firms' choice of product quality. Also, countries are grouped by their regulatory quality since there could be alternative ways to escape from competition, like lobbying (Bombardini et al., 2021), in countries with weaker regulatory quality. Relatedly, but extending these approaches, this paper asks whether where competition intensifies matters and what the potential drivers of the heterogeneity.

Empirical results are summarized as follows. First, the overall impact of export competition with China on South Korean firms' innovation is positive, whereas that of import competition is not clear between 2001 and 2007. Second, the innovation response is heterogeneous across firms in that only high productivity firms increase innovation as the theoretical model predicts. This tendency is more consistent for export competition. Third, the impact of export competition is heterogeneous across destinations in that South Korean firms increase innovation only in response to competition in countries where Korea leads China. At the same time, it is also found that only competition in countries with higher income, larger size, greater distance from Korea, and superior regulatory quality increases innovation, while income turns out to be more important than size, distance, and regulatory quality.

2 Reltated Literature

The broadest area this paper fits into studies the relationship between competition and innovation, which is still inconclusive.[6] Theoretically, more intense competition can either decrease innovation by reducing potential rents from innovating (Schumpeter, 1942) or can increase innovation by reducing pre-innovation rents more than post-innovation rents (Arrow, 1962). Incorporating these two opposite views, Aghion et al. (2005) suggest that competition and innovation have an inverted-U shape relationship since competition changes the equilibrium composition of firms who are active and inactive in innovation.

Narrowing the scope, this paper is closely related to the literature examining the innovation consequences of the China shock, which provides mixed evidence. For example, Autor et al. (2020) show that firms in sectors with higher exposure to Chinese imports reduce R&D intensity and patent production in the United States. However, Bloom et al. (2016) show that patents, IT intensity, TFP growth, and R&D expenditures increase in response to the rise of Chinese imports in European countries. Similarly, Medina (2017) show that Peruvian apparel manufacturers upgrade their product quality in response to the import competition with China. In contrast, Vancauteren et al. (2019) show that more intense import competition with China does not have a significant impact on patent applications of Dutch manufacturing firms. For South Korea, Ahn et al. (2018) show that patenting increases in response to Chinese import competition. However, none of these investigate the intensifying competition with Chinese firms in foreign markets that this paper emphasizes.

There are papers examining the impact of competition with China in export markets. For instance, how an increase in the US imports from China affects labor market outcomes (Utar and Ruiz, 2013; Mendez, 2015; Robertson et al., 2020), firm activities (Iacovone et al., 2011, 2013), migration (Majlesi and Narciso, 2018), female bargaining power (Majlesi, 2016),

[6] For reviews on competition and innovation, see Gilbert (2006) and Cohen (2010). One of the important sources of competition that has been actively investigated is international trade. See Shu and Steinwender (2019), Melitz and Redding (2021), and Akcigit and Melitz (2022) for reviews on trade and innovation.

and crimes (Dell et al., 2019) in Mexico have been examined.[7] More recently, Ding et al. (2022) investigate the impact of rising Chinese share in European markets on US firms.[8] However, all of these focus on a single export market, the United States or Europe. Instead, this paper takes all export markets into account, both theoretically and empirically, to capture a complete picture of competition with China.[9] Importantly, by considering all markets, it becomes feasible to answer whether competition in certain markets holds greater significance in firms' innovation, which has not been explored in the literature.

By investigating this heterogeneity across export destinations, this paper adds to the literature on competition and innovation (Aghion et al., 2005, 2009, and subsequent works) and extends a line of research on the importance of export destination. Regarding competition and innovation, even though a firm could be a leader in one market and be a laggard in another market for a variety of reasons, this possibility has not been importantly considered when examining how competition affects innovation. This paper addresses this gap by leveraging the worldwide rise of imports from China as an example that firms experience in multiple markets, where they may lead or lag. Through this approach, the role of market leadership on the relationship between competition and innovation is examined utilizing the same firm's response, thereby mitigating concerns about confounding factors.

Regarding the importance of export destination, while theoretical models propose various potential explanations for why firms export different quality of products to different markets — including factors such as income (Verhoogen, 2008) and transportation costs (Alchian and Allen, 1964; Feenstra and Romalis, 2014) — empirical evidence highlights the income of export destinations as a consistent and robust driver by showing that firms export better quality of products to richer countries.[10] However, this strand of research does not

[7]Among these, Iacovone et al. (2011) and Utar and Ruiz (2013) use outcome variables most closely related to innovation, enhancing management strategies.

[8]The authors focus on the change of Chinese share in Europe not because of Europe's importance as an export market but because of its exogeneity to US firms' decision.

[9]An exception is Choi et al. (2022) who build on the export competition measure developed in this paper to construct a plant-level export competition measure. They show that import competition and export competition with China affect multi-product plants' product switching behavior.

[10]For instance, see Manova and Zhang (2012), Brambilla et al. (2012), Brambilla and Porto (2016), and

answer how firms respond to rising competition in their export destinations, and whether the response is different across export destinations with different characteristics. This paper analyzes this under-studied question focusing on the relative importance of export destination characteristics that affect firms' innovation decision.

This study is also relevant to the literature that studies the heterogeneous innovation responses across firms to trade-related shocks, which tends to show that more productive firms engage in more innovation in response to shocks both theoretically and empirically. For instance, Bustos (2011) shows that only high-productivity firms adopt advanced technology due to the fixed cost of adoption when trade liberalizes using Argentinian data. Bombardini et al. (2017) also show that the impact of import competition in China is heterogeneous across firms in that only those close to the technology frontier increase innovation. Considering the growth of export market as a shock, Aghion et al. (2018) argue that high-productivity firms innovate more than low-productivity firms as a result of the rising competition between producers. French data confirm this prediction of heterogeneous innovation. The current paper complements these approaches by exploring a different channel and different environments.

3 Theoretical Model

3.1 Environment

There are S countries, all of which comprise two sectors: a homogeneous good sector and a differentiated good sector. Both goods are tradable without trade costs. Each country s is populated with L_s consumers who inelastically supply one unit of labor. For simplicity, assume that labor is immobile across borders, but mobile across sectors. Then, due to the homogeneous good sector, which requires one unit of labor to produce one product, wage in each country is normalized to one in equilibrium. In the differentiated sector, a continuum of firms is exposed to monopolistic competition with constant elasticity of substitution (CES) demand, which incorporates the preferences for quality. Firms are characterized by

Bastos et al. (2018). Also, see Verhoogen (2023) for a review.

productivity ϕ, which determines their production costs together with the quality of the product they choose. More specifically, production costs are decreasing in productivity and increasing in product quality. Upon entry after paying the fixed entry cost F_e, each firm draws ϕ from a known distribution $G(\phi)$ as in Melitz (2003).

3.2 Consumer Problem

The utility function of a representative consumer in country s is:

$$U_s = \rho_s^0 lnq_s^0 + \rho_s^1 lnQ_s \quad \text{where } \rho_s^0 + \rho_s^1 = 1\,,\ \ \rho_s^0, \rho_s^1 \geq 0 \tag{1}$$

where q_s^0 is the consumption of the homogeneous good. Q_s is a Dixit-Stiglitz aggregator over consumption bundles Q_{ks}, sourced from country k, each of which combines differentiated goods incorporating quality preferences:[11]

$$Q_s = \left(\sum_k Q_{ks}^{\frac{\sigma_s-1}{\sigma_s}}\right)^{\frac{\sigma_s}{\sigma_s-1}}, \text{ where } Q_{ks} = \left[\int_{\omega\in\Omega_{ks}} \left(z_{ks}(\omega)^{\delta_s} q_{ks}(\omega)\right)^{\frac{\sigma_s-1}{\sigma_s}} d\omega\right]^{\frac{\sigma_s}{\sigma_s-1}} \text{ and } \sigma_s > 1 \tag{2}$$

where subscript k indicates the source country and subscript s is assigned to the destination country. Using these country subscripts, $z_{ks}(\omega)$ means an index of the quality of variety ω that is imported from k to s, and δ_s indicates the intensity of quality preferences in s. δ_s is assumed to be positive so that consumers value product quality.[12] σ_s is the elasticity of substitution between products in s, and Ω_{ks} is the set of varieties that s imports from k.[13] Noting that the consumer spends ρ_s^1 fraction of her normalized income on differentiated products as implied by the Cobb-Douglas utility function (1), the demand function (per consumer) for variety ω can be derived as

$$q_{ks}(\omega) = p_{ks}(\omega)^{-\sigma_s} z_{ks}(\omega)^{\delta_s(\sigma_s-1)} \rho_s^1 P_s^{\sigma_s-1}, \tag{3}$$

[11]Quality preferences are introduced in various ways. Examples include Hallak (2006), Verhoogen (2008), Hallak and Schott (2011), Feenstra and Romalis (2014), and Antoniades (2015).

[12]When $\delta_s = 0$, consumers have the traditional CES preferences.

[13]Source country k includes the destination country s itself.

where $p_{ks}(\omega)$ is the price of variety ω. P_s, the quality adjusted price index of differentiated products in country s, is defined as the aggregate of P_{ks}, which is the price index of imports from k:

$$P_s = \left(\sum_k P_{ks}^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}}, \text{ where } P_{ks} = \left[\int_{\omega \in \Omega_{ks}} z_{ks}(\omega)^{\delta_s(\sigma_s - 1)} p_{ks}(\omega)^{1-\sigma_s} d\omega \right]^{\frac{1}{1-\sigma_s}}. \quad (4)$$

Intuitively, demand is decreasing in price and increasing in quality. Since there are L_s identical consumers in each market s, the total demand that country k's firm selling ω faces in market s is $L_s q_{ks}(\omega)$.

3.3 Firm Problem

Following Feenstra and Romalis (2014), firms may choose different product quality for each destination. Both marginal costs and fixed costs are increasing in product quality similar to Hallak and Sivadasan (2013). Noting that each firm is characterized by its productivity ϕ, the marginal costs that country k's firm with productivity ϕ should pay to sell its product to market s are

$$c_{ks}(\phi) = \frac{z_{ks}(\phi)}{\phi}, \quad (5)$$

which shows that it costs more to produce a good with higher quality. At the same time, (5) reflects that a firm with higher ϕ can produce the same product at lower marginal costs. In addition, to sell in market s, the firm has to pay fixed costs:

$$F_{ks}(\phi) = F_{ks} + f_{ks} z_{ks}(\phi)^{\alpha} \quad \text{where } \alpha > 0, \quad (6)$$

where F_{ks} is a part of fixed costs that does not depend on quality, and f_{ks} is a part of fixed costs that interacts with quality.[14] Fixed costs are destination-specific, and the quality-

[14] Quality-dependent fixed costs may include both tangible and intangible components. For instance, maintaining high-quality equipment, training workers, and paying a licensing fee for using advanced technology to produce high-quality products increase fixed costs.

elasticity of fixed costs α is assumed to be positive.[15] Therefore, fixed costs are higher for firms producing higher quality products and may vary across destinations.

This destination-specific cost structure implies that a firm's choice in one market does not affect its choice in other markets. Therefore, a firm chooses which markets to serve and maximizes its profits in each destination independently. More specifically, a firm with ϕ chooses the price and the quality of its product for market s considering the demand function (3) to maximize its profits from market s. Given this, the firm problem for market s can be written as follows omitting the origin subscript k for the simplicity of notation[16]:

$$\underset{p_s(\phi),z_s(\phi)}{Max} \left\{(p_s(\phi) - c_s(\phi))L_s p_s(\phi)^{-\sigma_s} z_s(\phi)^{\delta_s(\sigma_s-1)} \rho_s^1 P_s^{\sigma_s-1} - F_s(\phi)\right\}. \tag{7}$$

Noting that standard optimization yields $p_s(\phi) = \frac{\sigma_s}{\sigma_s-1}c_s(\phi) = \frac{\sigma_s}{\sigma_s-1}\frac{z_s(\phi)}{\phi}$, the maximization problem reduces to choosing just $z_s(\phi)$

$$\underset{z_s(\phi)}{Max} \left\{\frac{L_s}{\sigma_s}\left(\frac{\sigma_s}{\sigma_s-1}\frac{z_s(\phi)}{\phi}\right)^{1-\sigma_s} z_s(\phi)^{\delta_s(\sigma_s-1)} P_s^{\sigma_s-1} - F_s - f_s z_s(\phi)^{\alpha}\right\}. \tag{8}$$

Using the first order condition, the optimal quality choice of a firm with ϕ is derived as

$$z_s(\phi) = \left[\frac{L_s(\delta_s-1)}{\alpha f_s}\left(\frac{\sigma_s-1}{\sigma_s}\right)^{\sigma_s} \phi^{\sigma_s-1} \rho_s^1 P_s^{\sigma_s-1}\right]^{\frac{1}{\beta_s}}, \text{ where } \beta_s \equiv \alpha - (\delta_s-1)(\sigma_s-1), \tag{9}$$

where $\delta_s > 1$ and $\beta_s > 0$ are assumed to guarantee that $z_s(\phi)$ is increasing in ϕ and decreasing in f_s. This assumption means that the intensity of quality preference δ_s is larger than one, but not too large to dominate the quality-elasticity of fixed cost α. Then, using (8) and (9), it can be shown that the profits a firm with ϕ earns from market s are

$$\pi_s(\phi) = \left[\left(\frac{\rho_s^1 L_s(\delta_s-1)}{\alpha f_s}\right)\left(\frac{\sigma_s-1}{\sigma_s}\right)^{\sigma_s}\right]^{\frac{\alpha}{\beta_s}} \frac{\beta_s f_s}{\alpha-\beta_s}\phi^{\xi_s} P_s^{\xi_s} - F_s, \text{ where } \xi_s \equiv \frac{\alpha(\sigma_s-1)}{\beta_s}. \tag{10}$$

[15] The quality-elasticity of fixed costs can be origin-specific α_k. However, a simpler notation α is used since it does not alter the conclusion.

[16] Since the behavior of firms from the same origin k is of interest, subscript k is omitted.

Note that ξ_s is always positive since $\beta_s > 0$ and $\sigma_s > 1$ are already assumed. Note further that ξ_s is increasing in δ_s as β_s is decreasing in δ_s. Since this is a key parameter for comparative statics, it will be discussed further in Section 3.6. Intuitively, profits earned from each market s is increasing in the effective market size $\rho_s^1 L_s$ and productivity ϕ. Summing up the profits from all markets, the total profits of a firm with ϕ becomes

$$\Pi(\phi) = \sum_s \pi_s(\phi) \tag{11}$$

3.4 Equilibrium

(1) Zero profit cutoff

The zero profit cutoff productivity ϕ_s is defined for each destination s as the level of ϕ such that $\pi_s(\phi) = 0$. Since $\pi_s(\phi)$ is increasing in ϕ, only firms with $\phi > \phi_s$ make positive profits selling to market s. Using (10), ϕ_s is derived as

$$\phi_s = \left\{ \frac{F_s}{\left[\left(\frac{\rho_s^1 L_s(\delta_s - 1)}{\alpha f_s} \right) \left(\frac{\sigma_s - 1}{\sigma_s} \right)^{\sigma_s} \right]^{\frac{\alpha}{\beta_s}} \frac{\beta_s f_s}{\alpha - \beta_s} P_s^{\xi_s}} \right\}^{\frac{1}{\xi_s}}. \tag{12}$$

Since there are S countries, each country has S cutoff productivities, and there are S^2 cutoff productivities in the model. However, (12) shows that P_s is the only endogenous variable that determines ϕ_s. To be more precise with notation, the cutoff productivities for country k's firms to sell in market s (i.e. ϕ_{ks}) are automatically determined as a function of P_s and exogenous parameters for all $k = 1, 2, .., S$. This suggests that the equilibrium ϕ_s can be found with S more equations, which are established by the free entry condition.

(2) Free entry condition

The free entry condition requires the expected profits to be the same as the fixed entry cost F_e in equilibrium. Noting that (10) can be written as $\pi_s(\phi) = \left[\left(\frac{\phi}{\phi_s} \right)^{\xi_s} - 1 \right] F_s$ using (12), the free entry condition becomes

$$\sum_s \int_{\phi_s}^{\infty} \left[\left(\frac{\phi}{\phi_s}\right)^{\xi_s} - 1 \right] F_s dG(\phi) = F_e, \tag{13}$$

where the left-hand side indicates the expected profits. Since the free entry condition is defined for each country, there are S different free entry conditions. Combining these with S unknowns from (12), all ϕ_s can be pinned down.

(3) Firm-level performance measures

Using the cutoff productivity ϕ_s, firm-level performance measures in market s are written as

$$z_s(\phi) = \left[\frac{F_s(\alpha - \beta_s)}{\beta_s f_s} \left(\frac{\phi}{\phi_s}\right)^{\xi_s} \right]^{\frac{1}{\alpha}} \tag{14}$$

$$p_s(\phi) = \frac{\sigma_s}{(\sigma_s - 1)\phi} \left[\frac{F_s(\alpha - \beta_s)}{\beta_s f_s} \left(\frac{\phi}{\phi_s}\right)^{\xi_s} \right]^{\frac{1}{\alpha}} \tag{15}$$

$$q_s(\phi) = \frac{\alpha f_s \phi}{L_s(\delta_s - 1)} \left[\frac{F_s(\alpha - \beta_s)}{\beta_s f_s} \left(\frac{\phi}{\phi_s}\right)^{\xi_s} \right]^{\frac{\alpha - 1}{\alpha}} \tag{16}$$

$$r_s(\phi) = \frac{\sigma_s \alpha F_s}{\beta_s} \left(\frac{\phi}{\phi_s}\right)^{\xi_s} \tag{17}$$

$$F_s(\phi) = \left[1 + \frac{\alpha - \beta_s}{\beta_s} \left(\frac{\phi}{\phi_s}\right)^{\xi_s} \right] F_s \tag{18}$$

$$\pi_s(\phi) = \left[\left(\frac{\phi}{\phi_s}\right)^{\xi_s} - 1 \right] F_s, \tag{19}$$

all of which depend on $\frac{\phi}{\phi_s}$. Product quality $z_s(\phi)$, revenues $r_s(\phi)$, and profits $\pi_s(\phi)$ of a firm are increasing in productivity ϕ, which is intuitive.[17]

[17] Three more things are also noteworthy. First, the price a firm charges in each market may increase or decrease in productivity depending on the parameter. More specifically, the price increases in ϕ when $\alpha < \delta_s(\sigma_s - 1)$. However, in the absence of quality preferences, heterogeneous firm models always predict a negative relationship between price and productivity. Interestingly, empirical evidence suggests mixed evidence (see Crozet et al. (2012) and Antoniades (2015) for relevant discussion). Second, the quantity a firm sells in each market can decrease in ϕ when $\alpha < \frac{\delta_s(\sigma_s - 1)}{\sigma_s}$. For instance, when product quality is very important, the most productive firm may sell only a small quantity of high quality product. Third, the fixed costs of a firm increases in productivity ϕ since firms with higher productivity produce higher

(4) Income-spending condition

Finally, the mass of entrants and the number of available varieties in each market are determined by the income-spending condition, which implies that the total income of a country is the same as the total spending of the country on domestic and imported products. Formally, it can be written as

$$L_s = \rho_s^0 L_s + \sum_k M_k \int_{\phi_{ks}}^{\infty} r_{ks}(\phi) dG(\phi), \tag{20}$$

where the left-hand side stands for the total income of country s, whereas the right-hand side indicates the total spending. First, since each consumer spends ρ_s^0 fraction of her income on the homogeneous good, $\rho_s^0 L_s$ is spent on the homogeneous sector. Second, among M_k firms entering the differentiated sector from country k, only firms with productivity higher than ϕ_{ks} sell their products in market s earning revenues $r_{ks}(\phi)$. Since the zero profit condition and the free entry condition determine ϕ_{ks} and $r_{ks}(\phi)$, (20) implies that there are S equations and S unknowns. Therefore, the mass of entrants M_k in each country can be derived. Then, since $1 - G(\phi_{ks})$ fraction of M_k entrants in country k can sell to market s, the number of varieties available in market s can be derived as

$$V_s = \sum_k M_k(1 - G(\phi_{ks})) \tag{21}$$

3.5 Innovation Decision

Now, assume that productivity-enhancing innovation is available. Assume further that innovation cost is quadratic in the probability of successful innovation as in Bombardini et al. (2017). More specifically, when a firm invests $C(I) = \frac{1}{2\nu} I^2$, its productivity ϕ increases to $\gamma\phi$, where $\gamma > 1$, with a probability of I.[18] Since productivity improvement applies to all

quality products. In real world, quality-related fixed costs are required for trade marks, licenses, worker training, intangible assets, or advertisement, which are gaining more importance. However, this feature is not emphasized in models without quality preferences.

[18] Note that choosing I is equivalent to choosing the level of innovation investment and innovation. In

products regardless of the destination, a firm with ϕ determines the level of $I(\phi)$ by solving

$$\underset{I(\phi)\in[0,1]}{Max}\left\{\Pi(\phi)+I(\phi)\big(\Pi(\gamma\phi)-\Pi(\phi)\big)-\frac{1}{2\nu}I(\phi)^2\right\}, \tag{22}$$

which reflects pre-innovation profits, the probability of success, the profit increase following successful innovation, and the cost of innovation investment. The first order condition yields

$$I(\phi)=\left[\sum_s\left(\pi_s(\gamma\phi)-\pi_s(\phi)\right)\right]\times\nu. \tag{23}$$

Therefore, the optimal level of innovation of a firm with ϕ is

$$I(\phi)=min\left\{1\,,\,\sum_s\left[\mathbf{1}(\phi<\phi_s<\gamma\phi)\Big[\Big(\frac{\gamma\phi}{\phi_s}\Big)^{\xi_s}-1\Big]F_s\nu+\mathbf{1}(\phi>\phi_s)(\gamma^{\xi_s}-1)\left(\frac{\phi}{\phi_s}\right)^{\xi_s}F_s\nu\right]\right\} \tag{24}$$

where $\mathbf{1}(\phi<\phi_s<\gamma\phi)=1$ when $\phi<\phi_s<\gamma\phi$, and $\mathbf{1}(\phi>\phi_s)=1$ when $\phi>\phi_s$. Note that firms with $\phi<\phi_s<\gamma\phi$ sell to new market s only if innovation succeeds. For simplicity, suppose that firms do not take this possibility into account.[19] Then, (24) simplifies to

$$I(\phi)=min\left\{1\,,\,\sum_s I_s(\phi)\right\},\quad \text{where } I_s(\phi)=\mathbf{1}(\phi>\phi_s)(\gamma^{\xi_s}-1)\left(\frac{\phi}{\phi_s}\right)^{\xi_s}F_s\nu. \tag{25}$$

$I(\phi)$ is increasing in ϕ for two reasons. First, at the intensive margin, each $I_s(\phi)$ is increasing in ϕ since ξ_s is assumed to be positive. Second, at the extensive margin, since firms with larger ϕ export to more destinations, more $I_s(\phi)$ with positive values are added. Importantly, this extensive margin does not exist in the closed economy and is limited when there are only two countries in the model. For more interesting cases, γ and ν are assumed to be in a range such that a threshold productivity above which all firms engage in $I(\phi)=1$ is very

[19]For instance, γ can be close to one. Then, $\big[\big(\frac{\gamma\phi}{\phi_s}\big)^{\xi_s}-1\big]F_s\nu$ will be small and the range of firms with $\phi<\phi_s<\gamma\phi$ should be narrow. Therefore, ignoring $\mathbf{1}(\phi<\phi_s<\gamma\phi)\big[\big(\frac{\gamma\phi}{\phi_s}\big)^{\xi_s}-1\big]F_s\nu$ would not be problematic. This assumption is for the mathematical convenience, and the main results do not change without this assumption.

high. By doing so, I focus on the range of ϕ where $I(\phi) < 1$, which simplifies (25) further to

$$I(\phi) = \sum_s I_s(\phi) \quad \text{where} \;\; I_s(\phi) = \mathbf{1}(\phi > \phi_s)(\gamma^{\xi_s} - 1)\left(\frac{\phi}{\phi_s}\right)^{\xi_s} F_s \nu. \tag{26}$$

This shows that the optimal level of innovation can be decomposed to the sum of contributions from each market where a firm is selling to. This is because a firm may sell its product to multiple countries, and innovation increases profits earned from those multiple markets. Therefore, when making an innovation decision, the firm considers the benefits of innovation enjoyed from all countries that it serves.

3.6 Competition and Innovation

To examine the impact of rising competition with Chinese firms on innovation, the quality intensity parameter δ_s is assumed to be increasing in the level of utility similar to Feenstra and Romalis (2014).[20] More formally, the intensity of quality preferences in country s is

$$\delta_s(U_s) = \delta_s^{\,0} + h_s(U_s)\ , \;\; \text{where} \;\; h_s'(U_s) > 0, \tag{27}$$

where $\delta_s^{\,0}$ is constant, whereas $h_s(U_s)$ is increasing in U_s. Then, the utility function (1) implicitly defines the representative consumer's utility. However, since $h_s(U_s)$ is monotonically increasing in U_s, and since $\delta_s(U_s)$ will be a constant value in equilibrium, (1) can be regarded as a direct utility function in solving consumer problem.[21] Therefore, every step taken in Section 3 holds except that δ_s, and therefore ξ_s will change as U_s changes.

Now, suppose that the number Chinese firms increases as a result of the structural changes related to its accession to the WTO. For instance, it could be due to the the Per-

[20]This assumption reflects empirical evidence on the positive relationship between quality preferences and income (Bils and Klenow, 2001; Hallak, 2006; Verhoogen, 2008; Bastos et al., 2018).

[21]It is similar to the *guess and verify* approach in macroeconomics. Suppose that the consumer guesses her equilibrium utility and takes δ_s corresponding to the guess in maximizing her utility. If the solved utility is not the same as her initial guess, she updates her belief and solves the problem again until the her guess is correct. In the end, when the guess is correct, (1) can be regarded as a direct utility function.

manent Normal Trade Relations (PNTR) status that the US Congress granted to China (Handley and Limão, 2017), or it could be due to the Chinese industrial policies or subsidies as is shown by Kalouptsidi (2018) and Barwick et al. (Forthcoming).[22] Its impact on market s served by Chinese firms can be summarized as the following proposition.

Proposition 1. In market s served by Chinese firms, the rise of China leads to:
(1) an increase in the cutoff productivity to sell in market s,
(2) an increase in ξ_s.

Proof. The price index of differentiated products in market s can be rewritten as

$$P_s = \left(P_{cn,s}^{1-\sigma_s} + \sum_{k \neq cn} P_{ks}^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}}, \text{ where} P_{cn,s} = \left(M_{cn} \int_{\phi_{cn,s}}^{\infty} z_{cn,s}(\phi)^{\delta_s(\sigma_s-1)} p_{cn,s}(\phi)^{1-\sigma_s} dG(\phi) \right)^{\frac{1}{1-\sigma_s}} \tag{28}$$

by separating out the price index of imports from China $P_{cn,s}$. Then, an exogenous increase in the number of Chinese firms M_{cn} decreases the Chinese component of price index $P_{cn,s}$, and therefore P_s. This fall in P_s directly reduces the profits of firms selling in market s as is clear from (10). Therefore, the cutoff productivity for selling in market s increases.

In addition, the fall in P_s has an indirect effect. Using the corresponding demand function, it can be shown that consumer's utility can be expressed as

$$U_s = \rho_s^0 ln q_s^0 + \rho_s^1 ln \rho_s^1 P_s^{-1}, \tag{29}$$

which is decreasing in P_s. This implies that the rise of China increases consumer's utility in country s. As a result of this utility increase, $\delta_s(U_s)$ and $\xi_s(U_s)$ become larger.[23] □

[22] Indeed, Amiti et al. (2020) show that growth of Chinese exports after its accession to the WTO is mostly driven by new firms entering export markets. Alternatively, the rise of China can modeled as an increase in the productivity of Chinese firms, which leads to the same conclusion as shown in Appendix 1.

[23] In general equilibrium, the rise of China leads to the entry adjustment, which changes the number of entrants, cutoff productivities, and prices for all countries. However, as long as P_s decreases as $P_{cn,s}$ falls, the conclusion is not affected.

Not surprisingly, the rise of Chinese firms leads to the decrease in prices in importing countries and imposes downward pressure on profits of competing firms, which increases the cutoff productivities to make positive profits. More interestingly, (19) shows that profits become more sensitive to productivity as ξ_s increases. As a result of the rise of Chinese firms, consumers in market s become wealthier, and they regard product quality more importantly. Therefore, the ability to produce high quality product becomes more important, and profits become more sensitive to productivity.

To examine the innovation consequence of this change, recall that the optimal level of innovation $I(\phi)$ can be decomposed into each market component $I_s(\phi)$ as in (26). This implies that the impact of more intense competition on innovation can be also decomposed into contributions from each market. Denoting the new level of $I(\phi)$ and $I_s(\phi)$ as $I^{new}(\phi)$ and $I_s^{new}(\phi)$, the innovation response to the rise of Chinese competitors is decomposed as

$$I^{new}(\phi) - I(\phi) = \sum_s \big(I_s^{new}(\phi) - I_s(\phi)\big). \tag{30}$$

Given this decomposition, Proposition 2 summarizes how each market component $I_s(\phi)$ responds to more intense competition with China in market s.

Proposition 2. An increase in competition with China in market s decreases $I_s(\phi)$ of low productivity firms and increases $I_s(\phi)$ of high productivity firms.

Proof. As shown in Proposition 1, the rise of Chinese competitors in market s increases ϕ_s and ξ_s. Denoting this larger ϕ_s and ξ_s as ϕ_s^{new} and ξ_s^{new}, the change in $I_s(\phi)$ is written as

$$I_s^{new}(\phi) - I_s(\phi) = \begin{cases} 0\,, \quad \text{when } \phi \le \phi_s \\ -(\gamma^{\xi_s} - 1)\left(\frac{\phi}{\phi_s}\right)^{\xi_s} F_s\nu\,, \quad \text{when } \phi_s < \phi \le \phi_s^{new} \\ F_s\nu\big[(\gamma^{\xi_s^{new}} - 1)\big(\frac{\phi}{\phi_s^{new}}\big)^{\xi_s^{new}} - (\gamma^{\xi_s} - 1)\big(\frac{\phi}{\phi_s}\big)^{\xi_s}\big]\,, \text{ when } \phi > \phi_s^{new}. \end{cases} \tag{31}$$

First, since firms with $\phi \leq \phi_s$ do not sell in market s before competition intensifies, tougher competition in market s does not affect the innovation of these firms. Second, the least productive firms selling in market s with $\phi_s < \phi \leq \phi_s^{new}$ exit market s and decrease innovation as ϕ_s increases following Proposition 1. Third, the response of surviving firms in market s with $\phi > \phi_s^{new}$ is heterogeneous across firms. To see this, note that innovation increases if and only if $(\gamma^{\xi_s^{new}} - 1)\big(\frac{\phi}{\phi_s^{new}}\big)^{\xi_s^{new}} > (\gamma^{\xi_s} - 1)\big(\frac{\phi}{\phi_s}\big)^{\xi_s}$, which is equivalent to

$$\frac{\gamma^{\xi_s^{new}} - 1}{\gamma^{\xi_s} - 1} \times \Big(\frac{\phi}{\phi_s}\Big)^{\xi_s^{new} - \xi_s} \times \Big(\frac{\phi_s}{\phi_s^{new}}\Big)^{\xi_s^{new}} > 1. \tag{32}$$

The first component of (32) implies that innovation may increase since $\gamma > 1$ and $\xi_s^{new} > \xi_s$. In contrast, the third component suggests that innovation could decrease since $\phi_s < \phi_s^{new}$. However, the second component shows that the innovation response is heterogeneous in that it increases in ϕ without bound. Therefore, due to these countervailing forces, for any given change in ϕ_s and ξ_s, there exists a threshold T_s such that innovation increases for all $\phi > T_s$. In consequence, $I_s(\phi)$ increases for firms with sufficiently high productivity.[24] $\square$

This proposition shows that $I_s^{new}(\phi) - I_s(\phi)$ is generally increasing in ϕ for all s.[25] The underlying mechanism is as follows. As competition escalates, firms want to differentiate their products by producing higher-quality products. As a result, the benefits of productivity-enhancing innovation become larger since innovation makes it cheaper to produce higher-quality products. However, since low-productivity firms cannot afford the fixed cost of innovation due to the downward pressure on profits, only high-productivity firms engage in more innovation. This *scale effect* increases the innovation gap between high-productivity and low-productivity firms as competition intensifies.

When only domestic market is considered, this is the only effect that explains how firms

[24] Indeed, this innovation response is not limited to firms in country k. Since all firms competing in market s are affected by competition with China, high productivity firms originated from other countries also engage in more innovation. As shown in Appendix, this productivity improvement decreases the price index P_s further, which strengthens Proposition 1 and therefore Proposition 2.

[25] It is decreasing when productivity is relatively low ($\phi \in [\phi_s, \phi_s^{new}]$).

change innovation facing the rise of China. However, since Chinese exports have increased worldwide, not only competition at home but also competition in export markets should be considered. To investigate the export competition clearly, the innovation response (30) is rewritten by separating the domestic market and export markets as follows:

$$I^{new}(\phi) - I(\phi) = \underbrace{I^{new}_{home}(\phi) - I_{home}(\phi)}_{contributions\,from\,import\,competition} + \underbrace{\sum_{s \neq home} \left(I^{new}_{s}(\phi) - I_s(\phi) \right)}_{contributions\,from\,export\,competition} . \tag{33}$$

This shows that the innovation response of firms to the rise of China can be decomposed into the contributions from import competition and those from export competition. Since Proposition 2 applies to all markets where a firm competes against China, $I^{new}_{s}(\phi) - I_s(\phi)$ in (33) is positive for firms with sufficiently high productivity. As this scale effect accumulates over export markets, firms with higher productivity increase innovation not only due to the domestic market component but also due to their export market components. By considering this *accumulation effect* at the extensive margin, the model predicts that high-productivity firms increase innovation further in response to tougher competition with China.

The model clearly predicts the heterogeneous innovation responses of firms to the rise of China. However, there remain two questions unanswered by the model. First, since low-productivity firms decrease innovation, whereas high-productivity firms increase innovation, the overall impact of competition on innovation is ambiguous. This is true for both import competition and export competition. Second, a more interesting unanswered question is the relative importance of import competition and export competition in firm's innovation. The innovation response decomposition (33) does not show which component is larger, leaving the relative importance of import competition and export competition ambiguous. Indeed, this ambiguous relative importance can be generalized to all markets. The decomposition (30) implies a possibility that some components could be larger than others, meaning that competition in some countries are more influential than others. However, it is ex-ante not clear which market is more important. These questions require an empirical examination.

4 Data

4.1 Data Sources, Matching, and Sample Restrictions

This paper relies on three major types of data: bilateral trade data, Korean patent data, and Korean firm-level financial data. To begin with, trade data are sourced from CEPII's BACI, where bilateral trade values for more than 5000 products classified by 6-digit Harmonized System (HS) are available. BACI provides a single figure of bilateral trade flow reconciling the inconsistency in exports and imports information found in its raw data source, the UN Comtrade. It also provides more consistent unit value data (Gaulier and Zignago, 2010).[26]

The Korea Intellectual Property Rights Information Service (KIPRIS) offers access to South Korean patent data dating back to 1948. This dataset provides details for each patent, such as the application date, applicant identifiers, technology classification, and citation information, among other elements. In this study, I exclusively analyze newly submitted patent applications, excluding other types like extensions, modifications, or the division of existing patents, in order to concentrate on new inventions.

This patent dataset is matched to a firm-level dataset KIS-VALUE, managed by the largest Korean credit rating agency, NICE Korean Information Service.[27]. Specifically, firms in these two datasets are matched by their administrative corporation registration numbers and business registration numbers using a concordance table sourced from KIPRIS, which links patent applicant IDs to corporation registration numbers and business registration numbers. A more detailed matching and cleaning process can be found in Appendix 2.[28]

Among these matched firms, the sample is restricted to manufacturing firms with at least one patent application between 2001 and 2007 for the following reasons. First, manufacturing

[26]To link 6-digit HS code with Korean Standard Industry Classification (KSIC), both classifications are converted to 4-digit International Standard Industry Classification (ISIC) code using concordance tables provided by the World Integrated Trade Solution and Statistics Korea.

[27]All South Korean companies subject to auditing requirements are included in this data set

[28]Lee et al. (2020) match Korean patent data to a different firm-level dataset Dataguide 5.0. Due to the availability of the concordance table provided by KIPRIS, and the updated citation information, this study includes more firms with better-matched citation information.

firms are considered as a suitable unit of analysis because they account for 88.0% of the matched patent applications during the sample period, and the China shock affects tradable sectors disproportionately. Second, the sample period begins in 2001 when China joined the WTO since the accelerated growth of Chinese exports following its accession to the WTO is regarded as an exogenous shock (Autor et al., 2013; Pierce and Schott, 2016). Also it is the year when South Korea recovered from the Asian financial crisis and paid back the bailout package. The sample period ends in 2007 to mitigate possible endogeneity arising from the Global Financial Crisis which greatly influenced both trade flows and innovation incentives.

4.2 Competition Measures

Competition with China is measured in two dimensions: export competition and import competition. Export competition with China that Korean firm f in industry i experiences at time t is

$$\Delta XC_{f,t} = \frac{X_{f,0}}{Y_{f,0}} \sum_{S} \frac{X_{i,0}^{KRtoS}}{\sum_{S'} X_{i,0}^{KRtoS'}} \Delta_g \frac{X_{i,t}^{CNtoS}}{M_{i,t}^{S}} \tag{34}$$

where $X_{f,0}$ and $Y_{f,0}$ are firm f's exports and sales at time 0, respectively.[29] Therefore, the first component $\frac{X_{f,0}}{Y_{f,0}}$ shows the firm's reliance on exports. This component captures that firms relying heavily on export markets perceive the rise of Chinese competitors in its export markets more seriously. Turning to the second component, $X_{i,0}^{KRtoS}$ indicates Korean exports to country S in industry i at time 0.[30] Therefore, $\frac{X_{i,0}^{KRtoS}}{\sum_{S'} X_{i,0}^{KRtoS'}}$ captures the importance of each market S to Korean exports in industry i at time 0. This reflects that competition in more important export destination countries should be more influential to exporting firms. Finally, the last component $\Delta_g \frac{X_{i,t}^{CNtoS}}{M_{i,t}^{S}}$ shows the four-year Davis-Haltiwanger growth rate of the Chinese share of imports in industry i at time t, which is the proxy for competition with China in country S.[31] By combining these components, this measure captures a firm's effective

[29] Time 0 is defined as 2000, the year before the sample period of interest begins.

[30] Third country S includes all countries except South Korea and China.

[31] Since long difference in percentage point does not capture the difference in the initial level, the Davis-Haltiwanger growth rate ($\Delta_g Y = \frac{Y_t - Y_{t-4}}{Y_t + Y_{t-4}} * 2$) is employed.

exposure to the weighted sum of competition with China in export markets, considering the importance of each export destination as a weighting factor.

Note that this measure incorporates the industry-level competition with the weighted sum of growth in Chinese exports in each export market and captures the firm-level effective exposure to this shock. Importantly, by keeping firm-level exposure to export markets and the weight of market S fixed at time 0, the time variation of this measure is solely driven by changes in Chinese share of imports in country S, which arise due to the changes in China or changes in importing country S. In this regard, the measure of export competition $\Delta XC_{f,t}$ is considered as exogenous to Korean firms' innovation decision.[32]

Analogously, import competition that firm f in industry i faces at time t is

$$\Delta IC_{f,t} = \left(1 - \frac{X_{f,0}}{Y_{f,0}}\right) \times \Delta_g \frac{X_{i,t}^{CNtoKR}}{M_{i,t}^{KR}} \tag{35}$$

where the first component shows the firm's exposure to competition with China in the domestic market. Similar to the export competition measure, the second component indicates the four-year Davis-Haltiwanger growth rate of Chinese share of imports in Korea, which captures the industry-level competition with China. However, unlike (34), this measure could potentially experience endogeneity issue, for instance due to common factors that simultaneously affect Chinese share of imports in Korea and Korean firms' innovation decision, although lagged shocks are used in the estimation since current innovation is not likely to affect past shocks. To mitigate this issue, Chinese share of imports in other countries[33] is employed to instrument (35) following Autor et al. (2013):

$$\Delta ICO_{f,t} = \left(1 - \frac{X_{f,0}}{Y_{f,0}}\right) \times \Delta_g \frac{X_{i,t}^{CNtoOTH}}{M_{i,t}^{OTH}} \tag{36}$$

[32] This approach is similar to the strategy employed by Autor et al. (2013), where they depend on the exogeneity of changes in other countries' imports from China to construct an instrumental variable.

[33] They are Australia, Denmark, Finland, Germany, Japan, New Zealand, Spain, and Switzerland.

4.3 Data description

Table 1 reveals the matching efficiency by presenting the number of firms in the sample, their contributions to the total corporate patents originating in Korea, and their proportions in terms of exports, sales, tangible assets, employment, and profits within manufacturing firms in KIS-VALUE. Among 12,076 manufacturing firms out of 31,178 firms in KIS-VALUE, 8,368 firms are matched and 3,985 firms are included in the final dataset. Sample firms cover slightly less than two thirds of total corporate innovation and account for at least 77% of exports, sales, tangible assets, and wages of manufacturing firms in KIS-VALUE.[34]

Table 1: Matching results

	Firms (count) (1)	Patents (%) (2)	Exports (%) (3)	Sales (%) (4)	Tangible assets (%) (5)	Wages (%) (6)
KISVALUE	31,178	76.2	-	-	-	-
Manufacturing	12,076	67.0	100	100	100	100
Matched mfg	8,368	67.0	99.3	92.6	94.0	89.9
Sample	3,985	66.2	94.6	82.2	84.2	77.0

Notes: Row 2 consists of manufacturing firms from the KIS-VALUE dataset, representing a subset of the firms in row 1. Row 3 encompasses manufacturing firms with patent IDs, while row 4 comprises firms included in the sample. Column (2) shows the contributions to the total Korea based corporate patent applications (in %) over the sample period. Columns (3)-(6) indicate the proportions of firms in each category relative to manufacturing firms in the KIS-VALUE dataset (in %) over the sample period. Firms are designated to sectors based on the time-invariant KSIC9 industry classification.

Table 2 reports the summary statistics for sample firms. Panel A shows that firms in the sample are heterogeneous in various dimensions. First, sample firms exhibit significant variation in size, as is indicated by the range in tangible assets from nearly zero to 32 billion dollars. Wile the average tangible assets is 44 million dollars, its standard deviation is around eleven times of its mean. This heterogeneity is similarly observed for wages and age. Second, sample firms' reliance on export markets varies significantly. Some firms solely make their revenues from the domestic market, while others earn their entire sales from abroad. Third, innovation variables show sizable heterogeneity. While firms apply for around 11.8 patents

[34] Observations with misreporting are dropped, which account for 0.8% of total corporate patents.

Table 2: Sample summary statistics

Variable	Obs.	Mean	SD	Min	Max
Panel A. Full sample					
Year	26,226	2004.11	1.99	2001	2007
Age	26,226	12.59	11.29	0	110
Tangible assets (millions USD)	24,963	44.01	485.92	0.00015	32,047.64
Wages (millions USD)	24,877	3.25	26.17	0.00002	1,229.04
Exports/sales (%)	26,226	0.06	0.18	0	1
Patent applications	26,226	11.84	264.31	0	16,999
Citation-weighted patent	26,226	20.73	465.99	0	28,886
ΔXC	26,226	0.03	0.11	-0.23	1.14
ΔIC	26,226	0.64	0.48	-1.70	1.86
Panel B. Exporters					
Year	3,997	2004.00	2.00	2001	2007
Age	3,997	24.69	14.58	1	110
Tangible assets (millions USD)	3,986	208.57	1176.62	0.0066	32,047.64
Wages (millions USD)	3,964	12.09	56.73	0.0718	1,229.04
Exports/sales (%)	3,997	0.28	0.30	0	1
Patent applications	3,997	54.23	578.04	0	16,999
Citation-weighted patent	3,997	92.54	1013.59	0	28,886
ΔXC	3,997	0.18	0.21	-0.23	1.14
ΔIC	3,997	0.42	0.43	-1.52	1.85
Panel C. Non-exporters					
Year	22,229	2004.13	1.98	2001	2007
Age	22,229	10.42	9.00	0	78
Tangible assets (millions USD)	20,977	12.74	108.87	0.00015	5,192.77
Wages (millions USD)	20,913	1.57	13.67	0.00002	949.07
Exports/sales (%)	22,229	0.02	0.10	0	1
Patent applications	22,229	4.22	148.22	0	12,248
Citation-weighted patent	22,229	7.82	265.34	0	20,317
ΔXC	22,229	0.00	0.00	0	0
ΔIC	22,229	0.68	0.48	-1.70	1.86

Notes: Sample includes manufacturing firms with at least one patent applications between 2001 and 2007. The year of application is used as the year of patenting for patent applications and citation-weighted patents. Exporters are defined as firms with positive exports in 2000.

on average each year, the number of applications ranges between 0 and 16,999, and its standard deviation is around 22 times larger than its mean. This tendency holds for citation-weighted patent applications,[35] which considers the quality of innovation. Finally, the measure of export competition and import competition with China vary significantly across firms. While the average export competition (import competition) is 0.03 (0.64), it ranges between -0.23 and 1.14 (-1.70 and 1.86) showing considerable heterogeneity.

Panel B and C of Table 2 reveal that the heterogeneity across firms becomes even more pronounced when exporting status is considered.[36] Around 15% of firms in the sample are exporting firms, and they tend to be older and larger in terms of tangible assets and wages compared to non-exporting firms. More importantly, exporting firms apply for about 12.9 times more patents than non-exporting firms on average. Consequently, even though the number of non-exporting firms is about 5.6 times larger than that of exporting firms in the sample, the total number of patent applications by exporting firms is around 2.3 times larger than that of non-exporting firms.

This heterogeneity, especially the concentration of innovation among exporters, highlights why it is crucial to investigate the role of export competition on innovation. As innovation is predominantly driven by exporters who are more profoundly influenced by export competition, it is anticipated that export competition can exert substantial effects on exporters' decision making, including innovation decisions. Therefore, considering the significant global expansion of Chinese exports, exploring the consequences of export competition is essential for gaining a comprehensive understanding of the innovation consequences of the China shock. Leaving the impact of export competition unexplored could potentially lead to an incomplete understanding of how shifts in competitive pressures, driven by increased Chinese exports, affect innovation.

[35] The citation-weighted patent assigns the same value for patents and citations following Trajtenberg (1990). Moreover, since old patents are likely to be cited for a longer time, I only count citations of the first five years after the application as in Bloom and Van Reenen (2002).

[36] Firms are classified as exporters if they have positive exports in 2000.

5 Baseline Analysis

5.1 Empirical Strategy

The measures developed in (34) and (35) are used to capture the magnitude of export competition and import competition that Korean firms experience, and therefore to identify the impact of competition with China on innovation. In order to address potential endogeneity associated with the import competition measure, the 2SLS strategy is employed using (36) as an instrument variable similar to the literature. Given that the export competition measure is exogenous to Korean firms' innovation decision by construction, the 2SLS regression results can be interpreted as causal.[37]

Nevertheless, to enhance the rigor of analysis, a measure of export market size similar to one introduced by Aghion et al. (2022) is included to control the growth in the size of third markets where Korean firms compete against China. If Chinese exports to a third country is driven by the growth of the country, the size of market left for South Korean exporters could expand even if imports from China increases in the country. In this case, the effective level of competition that Korean exporters perceive in that market may not necessarily rise even though the export competition measure indicates a higher value. To mitigate this concern, the following measure is included for firm f in industry i in year t:

$$\Delta Xsize_{f,t} = \frac{X_{f,0}}{Y_{f,0}} \sum_{S} \frac{X_{i,0}^{KRtoS}}{\sum_{S'} X_{i,0}^{KRtoS'}} \times \Delta_g M_{i,t}^{S\setminus KR}, \tag{37}$$

where $M_{i,t}^{S\setminus KR}$ is the imports of country S from all countries except South Korea. Therefore, (37) considers the firm's initial exposure to export markets, the importance of each export destination, and the growth of non-Korean imports in each market that is exogenous to Korean firms' decision. To focus on the pure competition effect, this measure is controlled

[37] Although the Chinese share of imports in each country is weighted by the country's importance to Korean exports, it is possible a mechanical correlation may exist between the export competition measure and the instrument variable. An alternative export competition measure without considering eight countries used for the instrument variable gives qualitatively similar results.

whenever the impact of export competition is estimated.[38]

The main prediction of the theoretical model is that only high-productivity firms increase innovation in response to stronger competition with China. However, the model leaves the overall impact and the relative importance of export competition and import competition an empirical question. To answer this question, the following equation is estimated to examine the overall impact of export competition and import competition with China:

$$\Delta N_{f,t} = \alpha \Delta XC_{f,t-1} + \beta \Delta IC_{f,t-1} + \gamma ln(1 + N_{f,0}) + X'_{f,t}\Lambda + \mu_t + \mu_i + \varepsilon_{f,t}. \tag{38}$$

In line with the competition measures, the David-Haltiwanger growth rate of the number of patent application between year t and $t-4$ is used as a dependent variable.[39] At the same time, the average number of pre-sample period (1998-2000) patent applications is included to control unobservable firm-level heterogeneity that affects the innovation outcome, and since firms with smaller patent stock tend to show greater change in growth rate even if the number of patent applications does not change dramatically. In doing so, since patent applications show a large dispersion across firms and since there are many zeroes, a logarithm is taken after adding one to the number of patent applications.

One-year lagged competition measures are included to reflect the delayed response of innovation to competition, and to mitigate potential endogeneity concern arising from using current shocks. Therefore, α and β capture the impact of export competition and import competition on innovation, respectively. Firm-level control variables $X'_{f,t}$ include one-year lagged measure of export market size measure, average pre-sample period (1998-2000) tangible assets, wages (all in logarithms), and the age of the firm. Macroeconomic shocks and sector-specific components are captured by the year fixed effect μ_t and the 2-digit industry fixed effect μ_i. $\varepsilon_{f,t}$ is an error term, and standard errors are clustered at the firm level.

The theoretical prediction of the heterogeneity across firms is examined by estimating

[38] The estimation results without controlling these variables are qualitatively similar.

[39] Four-year growth rate is adopted to consider the time spent to innovate in response to competition with China, but qualitatively similar results are obtained when different time window is used.

the following equation:

$$\Delta N_{f,t} = \alpha_1 \Delta XC_{f,t-1} + \alpha_2 \Delta XC_{f,t-1} \times High_f + \beta_1 \Delta IC_{f,t-1} + \beta_2 \Delta IC_{f,t-1} \times High_f + \zeta High_f + \gamma \ln(1 + N_{f,0}) + X'_{f,t}\Lambda + \mu_t + \mu_i + \varepsilon_{f,t}, \quad (39)$$

where $High_f$ is an indicator of firms with the top quartile labor productivity (sales per employee) as of 2000 within the 2-digit industry.[40] By adding the interaction terms, (39) examines the heterogeneous impact of competition across firms. More specifically, α_1 captures the innovation response of firms with low productivity to export competition shock, and α_2 captures the heterogeneous response by firms with high productivity. Similarly, β_1 shows the impact of import competition on low productivity firms, and the heterogeneous responses by firms with higher productivity are captured by β_2.

5.2 Results

Table 3 shows the estimation results of (38) including either $\Delta IC_{f,t-1}$, $\Delta XC_{f,t-1}$, or both measures. Columns (2) and (5) show the 2SLS results, whereas the rest columns report the ordinary least squares (OLS) results. Two things are noteworthy. First, all coefficients related to import competition are not significant. The overall impact of import competition on innovation, which theoretical models and the empirical evidence in the literature are not clear about, turns out to be indistinguishable from zero. Second, more interestingly, all coefficients associated with export competition are positive and significant at the five percent level unlike the insignificant import competition coefficients. On average, the innovation of South Korean firms during the sample period is more responsive to export competition than to import competition, and the response is positive. These results are striking given the little attention that economists have paid to the role of export competition.

[40] Sales per employee may not reflect a firm's labor productivity when capital intensity differs significantly by firms. However, this problem is much less severe within the same industry where production technology and therefore capital intensity is similar. In practice, 0 is assigned to firms whose sales per employee cannot be computed. Dropping observations without sales per employee information does not change the results.

Table 3: Overall impact of competition with China on innovation

	OLS	2SLS	OLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)
$\Delta IC_{f,t-1}$	-0.011	0.004		-0.001	0.039
	(0.020)	(0.055)		(0.021)	(0.061)
$\Delta XC_{f,t-1}$			0.302**	0.301**	0.329**
			(0.152)	(0.153)	(0.157)
1st stage F-statistics		621.0			524.5
N	20,531	20,531	20,531	20,531	20,531

Notes: This table reports the estimated coefficients for equation (38) using the growth of patent applications as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. All models include year fixed effects, 2-digit industry fixed effects, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Columns (3)-(5) include the lagged growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

More specifically, in contrast to the insignificant import competition coefficients in column (1) and column (2), the export competition coefficient in column (3) is 0.302 and significant at the five percent level, showing that firms facing more intense export competition with China respond by increasing innovation. The export competition coefficient barely changes and remains significant in column (4) when both export competition and import competition are considered to examine the differential impact of each shock. Similarly, the 2SLS results in column (5) also show that only export competition has significant and positive impact on innovation at the five percent level. Quantitatively speaking, the export competition coefficient in column (5), the most preferred specification, implies that one standard deviation stronger export competition shock leads to 3.4 percentage points faster growth in patent applications.[41] Considering the strong first stage F-statistics and the exogeneity of $\Delta XC_{f,t-1}$, these results can be interpreted as causal.

Table 4 shows the heterogeneous impact of competition across firms. These results indicate that only high productivity firms increase innovation, and the response is dominated

[41] Since the standard deviation of export competition is 0.104, the impact of one standard deviation stronger export competition shock is computed by $0.104 \times 0.329 \times 100 = 3.4$.

by export competition. Coefficients associated with high productivity firms' response to export competition are precisely estimated, whereas all other coefficients are statistically insignificant. As is predicted by the theoretical model, only firms with higher initial productivity increase innovation responding to competition. In addition, despite the model's ex-ante ambiguous prediction on the relative importance of import competition and export competition, this empirical evidence highlights the importance of export competition again.

Table 4: Heterogeneous impact of competition with China on innovation

	OLS (1)	2SLS (2)	OLS (3)	OLS (4)	2SLS (5)
$\Delta IC_{f,t-1}$	-0.009	-0.008		-0.005	0.013
	(0.021)	(0.057)		(0.022)	(0.062)
$\Delta IC_{f,t-1} \times High_f$	-0.011	0.059		0.022	0.139
	(0.048)	(0.095)		(0.049)	(0.103)
$\Delta XC_{f,t-1}$			0.151	0.145	0.146
			(0.163)	(0.164)	(0.170)
$\Delta XC_{f,t-1} \times High_f$			0.420**	0.437**	0.528***
			(0.184)	(0.187)	(0.199)
1st stage F-statistics		302.7			237.0
N	20,531	20,531	20,531	20,531	20,531

Notes: This table reports the estimated coefficients for equation (39) using the growth of patent applications as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. Firms with the top quartile productivity within the 2-digit industry in 2000 are classified as high-productivity firms. All models include year fixed effects, 2-digit industry fixed effects, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Columns (3)-(5) include the lagged growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

More specifically, unlike the insignificant coefficients in columns (1) and (2), column (3) shows that export competition coefficient associated with high-productivity firms' stronger response is 0.420 and significant at the five percent level, whereas the coefficient related to low-productivity firms is not distinguishable from zero. This implies that only high-productivity firms increase innovation responding to export competition confirming the theoretical prediction. Columns (4) and (5) show that, only export competition coefficients associated with high-productivity firms are significant at least at the five percent level, meaning that high-productivity firms increase innovation, and the response is driven by the export competition channel. Quantitatively speaking, the export competition coefficients in column (5), the most preferred specification, imply that one standard deviation stronger export competition shock leads low productivity firms' patent applications to grow faster by 1.52 percentage points (although insignificant), whereas those of high productivity firms grow faster by 7.01 percentage points.

These findings highlight that the rise of China increased South Korean firms' innovation, in particular that of high-productivity firms, through the export competition channel during the sample period. To understand why innovation response is dominated by export competition, a further investigation is necessary. However, there are potential candidates such as the size of the export market relative to the domestic market, and different quality preferences in home and foreign markets, all of which could make firms respond differently to the rise of competition in each market. It is also possible that firms engage in different strategies to compete with China in each market. For instance, firms may build trade barriers in their domestic market through lobbying, whereas the same firms may focus on innovation to compete against China in their export markets. The next section explores potential factors that firms perceive importantly in their innovation decision.

6 Heterogeneity by Export Destinations

6.1 Economic Rationale and Empirical Strategy

The theoretical model implies that the change in innovation can be decomposed into contributions from each market as shown in (30). This theoretical decomposition allows to examine the potential heterogeneity between destination countries to better understand the previous results. More specifically, in the global economy, firms are competing against each other in multiple heterogeneous markets, which implies that the importance of each market, the possibility to escape from competition in each market through innovation, and therefore the best strategy to cope with competition could differ by market even for the same firm. Therefore, it is possible that competition in some countries could be systematically more important for a firm's innovation decision than competition in other countries. Investigating this possibility sheds light on the factors firms consider importantly in their innovation decision and therefore could be informative in understanding the relationship between competition and innovation. This is an important advantage of studying export competition with China because it allows researchers to analyze how competition rising in multiple markets with heterogeneous conditions affect the same firm's innovation decision differently.

Formally, motivated by the theoretical decomposition of export competition by countries, the export competition measure developed in the main analysis is decomposed into competition in two groups of countries with similar characteristics:

$$\Delta XC_{f,t}^{H} = \frac{X_{f,0}}{Y_{f,0}} \sum_{S \in H} \frac{X_{i,0}^{KRtoS}}{\sum_{S'} X_{i,0}^{KRtoS'}} \Delta_g \frac{X_{i,t-1}^{CNtoS}}{M_{i,t}^{S}} \quad \text{and} \tag{40}$$

$$\Delta XC_{f,t}^{L} = \frac{X_{f,0}}{Y_{f,0}} \sum_{S \in L} \frac{X_{i,0}^{KRtoS}}{\sum_{S'} X_{i,0}^{KRtoS'}} \Delta_g \frac{X_{i,t-1}^{CNtoS}}{M_{i,t}^{S}}, \tag{41}$$

where countries in group H and L are mutually exclusive. Equipped with these export competition measures, the following equation is estimated:

$$\Delta N_{f,t} = \alpha_1 \Delta XC_{f,t-1}^{H} + \alpha_2 \Delta XC_{f,t-1}^{L} + \beta \Delta IC_{f,t-1} + \gamma ln(1+N_{f,0}) + X'_{f,t}\Lambda + \mu_t + \mu_i + \varepsilon_{f,t}. \tag{42}$$

Similar to the main analysis, the four-year Davis-Haltiwanger growth rate of patent applications is used as a dependent variable. All control variables and fixed effects consistent with the main analysis are included, and the standard errors are clustered at the firm-level. To see the role of heterogeneity across export destinations in Korean firms' innovation decision, export markets are grouped based on the following characteristics.

First, the share of imports from China and Korea is used to identify markets where

Korean firms lead Chinese competitors initially.[42] More specifically, a country is classified as H if Chinese share of imports is smaller than Korean share of imports in 2000, whereas it is categorized as L if Korean share is smaller than Chinese share of imports for each industry. The theoretical rationale for this categorization stems from Aghion et al. (2005) who develop a model that laggards do not have incentives to innovate, and Aghion et al. (2009) who show that foreign competition from entry spurs innovation of incumbents only in leading sectors because innovation in laggard sectors is not profitable enough to offset the adverse impact of competition. This implies that the rise of China in markets where South Korean firms are leaders could increase innovation, whereas tougher competition with China in laggard markets may not provide enough incentives to innovate. Similarly, Lim et al. (2022) develop a theory that firms may innovate to escape from competition if less-competitive firms are catching up. These studies suggest that competition with China in countries where South Korean firms are leaders (H) could encourage innovation, whereas competition in countries where they are laggards (L) may not affect firms' innovation decision.

Second, motivated by the growing literature on the relationship between product quality and export destination characteristics, countries are grouped as high-income (H) and low-income (L) using the global median GDP per capita as a threshold.[43] Empirical evidence suggests that firms export higher quality of products to richer countries (Manova and Zhang, 2012; Brambilla et al., 2012; Brambilla and Porto, 2016; Bastos et al., 2018), while the income-based quality preference is emphasized as a potential driver of this quality choice. Since the theoretical model developed in this paper captures the income-based quality preference channel of the China shock and the quality-upgrading motivation of innovation, the income of export destination could be relevant for firms' innovation response to competition, but this potential heterogeneity is ex-ante not clear.

Third, investigating alternative drivers of firms' quality choice for each export des-

[42]This is done at the country-industry level. The same country can be classified as H in some industries and as L in other industries.

[43]The World Bank's World Development Index data provide GDP and GDP per capita information for 199 countries as of 2000. Those without this information are dropped.

tination, countries are categorized by the size of country and the distance from Korea. More specifically, countries with GDP above the global median are categorized as large (H), whereas those with GDP below the global median are grouped as small (L). In addition, the median bilateral distance between Korea and other countries is used as a cutoff to group countries as distant (H) and proximate (L).[44] Firms may export products of higher quality to larger countries if there are scale effects arising from fixed costs of producing better quality. At the same time, per-unit shipping costs may lead firms to export high quality products to more distant countries, which is known as the "Washington apples" effect (Alchian and Allen, 1964). Again, however, whether the rise of competition with China in larger or more distant countries has different impact on firms' innovation decision is an empirical question.

Lastly, regulatory quality measured by the World Bank's Worldwide Governance Indicators[45] is used to categorize export destinations as those with above-median regulatory quality (H) and those with below-median regulatory quality (L).[46] This idea originates from an alternative strategy that firms can rely on to escape from tougher competition with China in export destination countries: lobbying (Bombardini et al., 2021). While both innovation and lobbying incur costs, the benefits of lobbying are arguably higher where regulatory quality is low, and therefore politicians can have a stronger influence. At the same time, the protection of intellectual property could be weaker in countries with less robust regulatory quality. This suggests that innovation is less likely to be employed as a strategy to escape from competition in markets where regulatory quality is weak (L).[47]

[44] The CERDI-seadistance database (Bertoli et al., 2016) provides the bilateral distances between countries based on the maritime distance from each country's capital city to the nearest large port and the road distance from the port to the capital city, both of which consider the shortest available routes. Admittedly, adding up these two distances may not precisely capture the effective distance between South Korea and other countries. However, this issue is less concerned in this context since the distance information is used to categorize countries into proximate and distant groups, rather than utilizing the exact distance. Moreover, since South Korea is geographically close to China, two countries have the similar optimal routes to reach their export destinations.

[45] Regulatory quality captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.

[46] In practice, if regulatory quality data is not available in 2000, the earliest following year's information is used. 182 countries have this data, and those without this information are dropped.

[47] Admittedly, high income countries are more likely to be large countries, be distant from Korea, and have better regulatory quality. This potential concern is addressed below.

6.2 Results

Table 5 shows the results by grouping export destinations as where Korea leads and where Korea lags. Columns (1) and (2) report the OLS results, whereas column (3) shows the 2SLS results. The results indicate that import competition does not have significant impact on innovation as in the main analysis, whereas export competition in markets where Korea leads China increases Korean firms' innovation. In contrast, export competition in markets where Korean firms are laggards does not have such an impact. All export coefficients of H group countries in the second row are positive and significant, whereas those of import competition and L group countries are statistically not distinguishable from zero.

Table 5: Heterogeneous impact of competition by market leadership

	OLS (1)	OLS (2)	2SLS (3)
$\Delta IC_{f,t-1}$		-0.001 (0.021)	0.039 (0.061)
$\Delta XC^H_{f,t-1}$	0.322* (0.167)	0.322* (0.167)	0.348** (0.171)
$\Delta XC^L_{f,t-1}$	0.214 (0.315)	0.213 (0.315)	0.248 (0.321)
1st stage F-statistics			524.3
N	20,531	20,531	20,531

Notes: This table reports the estimated coefficients for equation (42) using the growth of patent applications as a dependent variable. Columns (1) and (2) report the OLS results, whereas column (3) reports the 2SLS results. Countries in group H are where Korean share of imports is larger than Chinese share. All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Catching up of Chinese firms in markets where Korean firms led Chinese firms increases innovation of Korean firms, whereas the widening gap between Korean firms and Chinese firms in markets where China was already leading does not result in an increased innovation. This empirical evidence reinforces the theoretical basis and the prediction of the literature, leaders are more likely to innovate facing tougher competition, by investigating the role of heterogeneous competition environments that the same firm faces on its innovation decision. In other words, this evidence implies that the role of market leadership on the relationship between competition and innovation could apply at the firm-destination level, which is more nuanced but stronger than the firm-level argument in the literature.

Now, turning to other export destination characteristics, Table 6 shows the 2SLS results for equation (42), where each column utilizes different categorization of countries. Group H includes countries with above-median GDP per capita in column (1), those with above-median GDP in column (2), those with above-median distance from Korea in column (3), and those with higher regulatory quality in column (4).

Table 6: Heterogeneous impact of competition with China by destination

	Income (1)	Size (2)	Distance (3)	Regulation (4)
$\Delta IC_{f,t-1}$	0.040	0.036	0.042	0.038
	(0.061)	(0.061)	(0.061)	(0.061)
$\Delta XC^H_{f,t-1}$	0.435**	0.358**	1.652***	0.357*
	(0.207)	(0.176)	(0.598)	(0.194)
$\Delta XC^L_{f,t-1}$	-0.010	1.331	-0.026	0.298
	(0.535)	(1.044)	(0.218)	(0.599)
1st stage F-statistics	518.1	526.7	523.3	518.7
N	20,531	20,531	20,531	20,531

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of patent applications as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Overall, the results indicate that import competition does not have significant impact on innovation as in the main analysis, whereas export competition in H group countries increases innovation regardless of the categorization. In contrast, export competition in L group countries does not have such an impact. All export coefficients of H group countries in the second row are positive and significant, whereas those of import competition and L group countries are statistically not distinguishable from zero. Taking a step further from the main analysis, which shows that export competition drives the innovation response of South Korean firms, these results narrow the driver to smaller number of export destinations with specific characteristics.

More specifically, column (1)-(3) show that competition with China in richer, larger, and more distant countries increases Korean firms' innovation, whereas tougher competition in other countries does not have statistically distinguishable impact on innovation. Unlike the ex-ante ambiguous prediction on the heterogeneous impact by export destinations, these results imply that income, size, and distance matter for firms' innovation decision.

Two questions arise from this point. First, why do firms increase innovation only in response to tougher competition in richer, larger, more distant destinations? Second, since richer countries are likely to be larger countries, and more distant from Korea, the positive and significant impact of export competition in countries grouped as richer, larger, and farther may not precisely capture the export destination characteristics firms consider in their innovation decision. This is also true for the positive and significant impact of export competition in countries with better regulatory quality in column (5). Correlation between income, size, distance from Korea, and regulatory quality may drive these results mechanically even if not all of them are important.

To address this correlation and to understand the mechanism better, 31 countries that are rich, large, distant from Korea, and have sound quality of regulation at the same time are dropped when constructing export competition measures in (40). Although dropping these countries may result in less precise estimation of the role of export competition given these countries' importance as export markets, this exercise allows to shed light on the relative importance of each factor, which is the goal of this section. Moreover, the United States, the largest export market to Korean firms, is not omitted as it is relatively close to Korea due to the Pacific Ocean route, which mitigates the concern from dropping countries.

Table 7 reports the estimated results. After dropping those export markets, the impact of export competition in larger countries, more distant countries, and countries with better regulatory quality on innovation are not significant anymore as shown in columns (2)-(4), whereas competition in richer countries still has positive and significant impact as in column (1), although it is significant only at the ten percent level. These results do not rule out the possibility that size, distance, and regulatory quality of export destination matter. However, these results do highlight the importance of richer markets in firm's innovation decision.

Table 7: Heterogeneity by destination for a subset of countries

	Income (1)	Size (2)	Distance (3)	Regulation (4)
$\Delta IC_{f,t-1}$	0.022	0.023	0.026	0.027
	(0.060)	(0.060)	(0.060)	(0.061)
$\Delta XC^{H}_{f,t-1}$	4.304*	0.459	1.000	0.446
	(2.349)	(0.568)	(0.973)	(0.504)
$\Delta XC^{L}_{f,t-1}$	-1.256	0.004	0.262	0.334
	(1.535)	(1.415)	(0.450)	(0.618)
1st stage F-statistics	546.2	546.8	543.2	527.5
N	20,531	20,531	20,531	20,531

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of patent applications as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). Countries that are rich, large, distant, and with high regulatory quality at the same time are excluded. All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Interpretation of these results can be guided by the robust empirical evidence in the literature pointing income-based quality preferences as a main driver of firms' product quality choice for different export markets (see Verhoogen, 2023, for a review) and the theoretical model developed in this paper. If product quality choice is determined by the income of export destination countries, if quality upgrading is the motivation of innovation as the theoretical model suggests, and if the rise of China makes consumers more sensitive to quality as the model assumes, then the empirical results in Table 7 imply that tougher competition in richer export markets incentivizes firms to innovate to upgrade the already high quality of their products targeting those richer destination. Appendix 3 shows that all findings in this section are robust after addressing potential concerns.

One possible reason explaining this story is that innovation determines the highest quality a firm can produce. If this is the case, tougher competition in markets where firms are selling their best product could lead to innovation to upgrade quality, whereas competition in low-income markets where they are not selling their best product due to weaker quality preferences may just result in switching products targeting those markets without innovation. However, this is only one of many possible approaches, and the analysis done here is far from exhaustive. Both theoretical and empirical research to uncover what export market characteristics are important and how firms employ different strategies considering the destination heterogeneity in response to tighter competition would be fruitful, which is beyond the scope of this paper.

7 Conclusion

How does the rise of China affect innovation in other countries? In answering this question, I emphasize the importance of *export competition*, which means competition in third countries. Given that competition with China in export markets has intensified significantly due to the global surge in Chinese exports, it is crucial to underscore this channel when analyzing the implications of the China syndrome. Surprisingly, however, the literature has rarely delved into this specific aspect, despite its potential to provide critical insights into the effects of China's rise on innovation.

To understand the export competition channel, I develop a multi-country model with innovation incorporating quality preferences of consumers and heterogeneous productivity of firms. The model predicts that more intense competition increases the innovation of high-productivity firms, whereas it reduces the innovation of low-productivity firms. This is because the downward pressure on profits prevents low-productivity firms from innovating even though competition encourages firms to innovate to upgrade their product quality. At the same time, it suggests a potential heterogeneity across markets where competition intensifies by decomposing firms' innovation response to contributions from each market.

Empirical evidence from South Korean patent data using a novel firm-level measure of export competition developed in this paper shows that export competition with China increases South Korean firms' innovation, whereas import competition does not have such an impact. The heterogeneity of these results are investigated in two dimensions. First, it is shown that only high-productivity firms increase innovation in response to more intense competition, especially to export competition, in line with the model's prediction. Then, the heterogeneity by export destinations is reported in that innovation increases only in response to export competition in markets where Korea leads China. Also, export competition in countries with higher income, larger size, greater distance from Korea, and superior regulatory quality is found to increase innovation, while destination countries' income shows more consistent results than others.

These results have meaningful implications in today's interconnected global economy, where firms compete against each other not only in their domestic market but also in their export markets. The dominance of export competition along with the heterogeneous responses across firms suggest an important channel through which trade shocks affect inequality across firms and concentration. Especially because innovation has a longer run consequence, it is crucial for policymakers to understand and accurately assess this channel in their decision making. In addition, the heterogeneous impact of competition across different export destinations implies the importance of broadly defined geography. Since firms that initially sell to richer destinations or have comparative advantages in many countries – for instance, owing to factors such as lower trade costs, geographical proximity, political alignment, or shared language – are more likely to increase innovation facing the rise of China, more remote countries are less likely to increase innovation in response to tougher competition with China.

Since innovation is an engine of growth, this could imply an uneven growth in a dynamic sense from the global perspective.

These implications naturally raise future research questions on distributional consequences of the China shock both within and across countries considering import competition, export competition, innovation, and the role of geography reflected in export destinations with better data. Beyond these direct questions, this study also can be extended to more general but interesting directions. To begin with, the readily applicable measure of export competition developed in this paper can be used to explore other outcomes and/or other countries. Considering the worldwide growth of Chinese exports over the past decades, there is no reason to limit the scope of research to South Korea and innovation. In addition, other competitive shocks can be explored to understand the export competition channel more clearly. Considering numerous historical episodes including trade liberalization, free trade agreements, industrial policies, commodity discoveries, economic sanctions, and trade conflicts, the rise or fall of competition in third markets should not be rare. At the same time, the factors that make firms respond more strongly to competition in certain markets and the optimal strategies that firms rely on to cope with competition in different markets also require further investigation both theoretically and empirically with a better data source.

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Appendix 1 Alternative source of competition: productivity approach

Instead of incorporating an increase in the number of Chinese firms as a source of competition, the impact of the productivity improvement of Chinese firms on innovation is examined. The quality intensity parameter δ_s is assumed to be endogenous in the level of utility as in the main text. Recall that the price index (4) can be rewritten as

$$P_s = \left(P_{cn,s}^{1-\sigma_s} + \sum_{k \neq cn} P_{ks}^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}}, \text{ where } P_{cn,s} = \left(M_{cn} \int_{\phi_{cn,s}}^{\infty} z_{cn,s}(\phi)^{\delta_s(\sigma_s-1)} p_{cn,s}(\phi)^{1-\sigma_s} dG(\phi) \right)^{\frac{1}{1-\sigma_s}}.$$

It can be shown that the quality adjusted prices that comprise $P_{cn,s}$ is

$$z_{cn,s}(\phi)^{\delta_s(\sigma_s-1)} p_{cn,s}^{1-\sigma_s} = \left(\frac{\sigma_s}{\sigma_s - 1}\right)^{1-\sigma_s} \left(\frac{F_s(\alpha - \beta_s)}{\beta_s f_s}\right)^{\frac{\alpha-\beta_s}{\alpha}} \phi^{\xi_s} \phi_s^{\frac{(\alpha-\beta_s)(\sigma_s-1)}{\beta_s}}, \tag{A1}$$

which is increasing in ϕ. Therefore, the quality adjusted prices of incumbent Chinese firms selling in market s fall when their productivity improves. As a result, the price index in country s falls similar to the main text. Then, the utility of consumers in country s increases, and Proposition 1, Proposition 2, and Proposition 3 of the main text hold. Furthermore, since this innovation response is not limited to Korean firms, high productivity firms of other countries engage in more innovation as well. Therefore, the second wave of productivity improvement follows the rise of Chinese firms. This general equilibrium effect accelerates the innovation of high-productivity firms further.

Appendix 2 Data Appendix

Appendix 2.1 KIPRIS - KISVALUE Matching

KIPRIS offers an Application Programming Interface (API) service that allows users to retrieve bibliographic details for the entire collection of South Korean patents dating back to 1948. By employing Python's "requests" command, one can access a comprehensive range of information, including application IDs, the names and addresses of assignees along with their unique identifiers, inventors' names and addresses, technology classifications, titles, abstracts, specific claims, registration statuses, types of applications, and citations.

When it comes to citation information, a challenge arises in linking citing patents to cited patents because the data is recorded using publication numbers or registration numbers, rather than application numbers. This issue becomes especially pertinent prior to the 2000s when publication numbers may not uniquely correspond to application numbers. Consequently, citation data have not been widely utilized in the context of South Korean patent data. However, KIPRIS has recently resolved this problem by establishing connections between citing and cited patents using application numbers, and this study relies on this updated information.

In practice, this research opts for citations selected by examiners over those provided by applicants, as the former is considered to be more indicative of patent quality. Additionally, to account for the fact that older patents are more likely to be cited over an extended period, only citations within the first five years following application are considered.

This patent information is then matched with the firm-level dataset KISVALUE, following these steps.

1. Download firm-level information from KISVALUE including corporation registration number and business registration number.

2. Download a concordance table from KIPRIS that links patent applicant IDs to corporation registration numbers and business registration numbers.

3. Match patent applicant IDs to corporation registration numbers and business registration numbers in the KISVALUE data. Then, two matched datasets are merged. Sometimes, at this step, one patent ID may be assigned to multiple firms. In that case, priority is given to observations matched with corporation registration numbers.

4. Use corporation registration numbers of the KISVALUE dataset to web-scrape patent applicant IDs on the Korean Intellectual Property Office website (http://patent.go.kr).

5. Combine matched observations obtained from step 3 and step 4, and drop duplicate observations to finalize the data.

Through these steps, 17,346 firms in the KISVALUE dataset are matched with patent applicant IDs. Importantly, each firm may have more than one patent ID since multiple IDs can be assigned to a firm due to name change, duplicate ID applications, or pure mistakes. Therefore, when patent IDs are used as firm-identifiers, patents of the same firm may be mistakenly regarded as those of different firms. By utilizing corporation registration numbers and business registration numbers, this problem can be mitigated in this study.

Appendix 2.2 KSIC - ISIC Matching

The 5-digit industry classification under the 9th revision of KSIC is aligned with the 4-digit industry classification according to the 3rd revision of ISIC, utilizing the concordance table provided by Statistics Korea. Since firms in the KISVALUE dataset report their industry at the 5-digit level, this concordance table is used to construct a firm-level export competition measure. However, some firms opt to report their industry at the 3-digit or 4-digit level. In such instances, multiple 4-digit ISIC industries may potentially considered as candidates for the firm's industry. To resolve this, the 4-digit ISIC industry matched to the 5-digit KSIC industry with the largest shipment value in 2007 is selected as the firm's industry. For instance, suppose a firm reports its industry as 31990, which encompasses both 31991 and 31999. Then, the potential candidates of the 4-digit ISIC industry are 3592 and 3599 since 31991 of KSIC is matched to 3592 of ISIC, whereas 31999 of KSIC is linked to 3599 of ISIC. In this case, since the shipment of 31991 industry is smaller than 31999 industry (18,338 million KRW versus 69,504 million KRW), the firm's industry is converted to 3599 ISIC industry.

Appendix 2.3 Data Correction for Competition Measures

Raw firm-level data and trade data are modified to construct the measures of export competition and import competition in a consistent manner. First, raw firm-level financial data are corrected since they include observations with the export share greater than one (exports/sales>1). When those observations have domestic sales information and the sum of domestic sales and exports is smaller than reported sales information, I replace the reported sales information with the sum of domestic sales and exports. After this correction, the export share is larger than one for 36 observations due to the lack of domestic sales data. These observations are dropped.

Second, raw trade data are modified to consider the partition of countries between the period of interest. More specifically, if partition happened during the sample period, trade flow related to those new countries are aggregated as if the partition did not happen. For instance, since Timore-Leste became independent from Indonesia in 2002, trade with Timore-Leste is added to trade with Indonesia. Similarly, since Serbia Montenegro became Serbia and Montenegro in 2006, these countries are considered as one country in the analysis.

Appendix 3 Robustness Check

Appendix 3.1 Falsification Test

Since innovation reflects general technological progress or obsolescence, it is possible that existing technological trends may drive the main results. More specifically, if firms that experience the rise of China in export markets are those innovate the most because they operate in sectors where technological progress is active, it is possible that existing trends may confound the impact of the China shock.[48] Indeed, Autor et al. (2020) claim that the failure in considering existing trend in estimating the impact of the China shock on innovation could be problematic. To mitigate this concern, the pre-sample-period innovation growth

[48] Although it is unclear why the import competition does not have similar impact as the export competition if this is the case.

between 1995 and 2000 is regressed on sample period shocks as a falsification test.[49] Since technological progress and obsolescence is a long-run cycle Eriksson et al. (2021), the impact of current China shock on the pre-period innovation growth is expected to be significant if the existing trends drive the main results.

Table A1 shows the results of estimating equation (38) using the pre-sample period patent. The import competition coefficient in column (2) is negative and significant at the ten percent level, but it is not significant when export competition is considered at the same time in columns (4) and (5). In addition, no export coefficients are significant. Although the number of observations is smaller than the main analysis due to the smaller number of observations with the pre-sample period information, these results suggest that the increase in innovation in response to tougher export competition with China found in the main analysis is not associated with the pre-existing trends in innovation.

Table A1: Overall impact of competition with China on past innovation

	OLS (1)	2SLS (2)	OLS (3)	OLS (4)	2SLS (5)
$\Delta IC_{f,t-1}$	-0.032	-0.174*		-0.027	-0.178
	(0.036)	(0.098)		(0.037)	(0.110)
$\Delta XC_{f,t-1}$			0.012	-0.003	-0.088
			(0.186)	(0.188)	(0.200)
1st stage F-statistics		160.0			132.0
N	5,916	5,916	5,916	5,916	5,916

Notes: This table reports the estimated coefficients for equation (38) using the growth of pre-sample period patent applications (1995-2000) as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. All models include year fixed effects, 2-digit industry fixed effects, age, and the pre-sample period (1991-1994) average wages, tangible assets, and patent applications (in logarithms). Columns (3)-(5) include the lagged growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Table A2 reports the falsification test results considering heterogeneity across firms

[49]For control variables, the average between 1991 and 1994 is used in line with the period that past innovation growth focuses on. Due to the control variable availability, only current period shocks between 2002 and 2007 are used.

by estimating equation (39) using the pre-sample period patent. No export competition coefficient is significant, mitigating the concern. In addition, although a coefficient in column (5), which shows high-productivity firms' response to import competition is significant, this coefficient is only weakly significant at the ten percent level, no statistically significant impact is found for import competition in the main analysis, and the sign is opposite from the theoretical prediction. Therefore, it is not likely that the main results are driven by pre-existing trend of innovation.

Table A2: Heterogeneous impact of competition with China on past innovation

	OLS (1)	2SLS (2)	OLS (3)	OLS (4)	2SLS (5)
$\Delta IC_{f,t-1}$	-0.046 (0.041)	-0.122 (0.100)		-0.038 (0.042)	-0.123 (0.111)
$\Delta IC_{f,t-1} \times High_f$	0.046 (0.067)	-0.211 (0.145)		0.035 (0.068)	-0.267* (0.159)
$\Delta XC_{f,t-1}$			0.117 (0.230)	0.091 (0.233)	0.076 (0.241)
$\Delta XC_{f,t-1} \times High_f$			-0.223 (0.222)	-0.201 (0.227)	-0.387 (0.249)
1st stage F-statistics		67.4			51.1
N	5,916	5,916	5,916	5,916	5,916

Notes: This table reports the estimated coefficients for equation (39) using the growth of pre-sample period patent applications (1995-2000) as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. Firms with the top quartile productivity within the 2-digit industry in 2000 are classified as high-productivity firms.. All models include year fixed effects, 2-digit industry fixed effects, age, and the pre-sample period (1991-1994) average wages, tangible assets, and patent applications (in logarithms). Columns (3)-(5) include the lagged growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Turning to the export destination heterogeneity, Table A3 shows the falsification test results considering which country has a leadership in each export market after estimating equation (42) using the pre-sample period patent. No coefficients are statistically significant implying that the differential importance of competition in markets where Korea leads China is not likely to be driven by pre-existing trend of innovation.

Table A3: Heterogeneous impact of competition with China by market leadership on past innovation

	OLS (1)	OLS (2)	2SLS (3)
$\Delta IC_{f,t-1}$		-0.028	-0.179
		(0.037)	(0.110)
$\Delta XC^{H}_{f,t-1}$	0.068	0.053	-0.027
	(0.200)	(0.202)	(0.214)
$\Delta XC^{L}_{f,t-1}$	-0.323	-0.343	-0.456
	(0.408)	(0.408)	(0.416)
1st stage F-statistics			131.8
N	5,916	5,916	5,916

Notes: This table reports the estimated coefficients for equation (42) using the growth of pre-sample period patent applications (1995-2000) as a dependent variable. Columns (1) and (2) report the OLS results, whereas column (3) reports the 2SLS results. Countries in group H are where Korean share of imports is larger than Chinese share. All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1991-1994) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Table A4 shows the falsification test results considering income, size, distance from Korea, and regulatory quality of export destinations after estimating equation (42) using the pre-sample period patent. No coefficients are statistically significant even after considering the differential importance of markets with higher income, larger size, greater distance from Korea, or better regulatory quality. Again, it is not likely that the previous results are driven by pre-existing trend of innovation.

Table A4: Heterogeneous impact of competition by destination on past innovation

	Income (1)	Size (2)	Distance (3)	Regulation (4)
$\Delta IC_{f,t-1}$	-0.176	-0.177	-0.179	-0.175
	(0.111)	(0.110)	(0.111)	(0.110)
$\Delta XC^{H}_{f,t-1}$	-0.069	-0.136	-0.229	-0.092
	(0.273)	(0.216)	(0.662)	(0.250)
$\Delta XC^{L}_{f,t-1}$	-0.535	-0.888	-0.064	-0.661
	(0.686)	(0.658)	(0.255)	(0.666)
1st stage F-statistics	130.4	132.4	131.7	130.5
N	5,916	5,916	5,916	5,916

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of pre-sample period patent applications (1995-2000) as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1991-1994) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Table A5 confirms these falsification test results by showing that even no coefficients are statistically significant after dropping countries with higher income, larger size, greater distance from Korea, and better regulatory quality. Assuringly, all results in this section indicate that the results in previous sections, the positive impact of export competition with China on innovation and the heterogeneity found across firms and export destinations, are not arising from the pre-existing trends in innovation.

Table A5: Heterogeneity by destination for a subset of countries on past innovation

	Income (1)	Size (2)	Distance (3)	Regulation (4)
$\Delta IC_{f,t-1}$	-0.169	-0.172	-0.175	-0.166
	(0.106)	(0.106)	(0.107)	(0.110)
$\Delta XC^{H}_{f,t-1}$	-1.568	-0.565	-0.583	0.143
	(1.329)	(0.698)	(0.957)	(0.640)
$\Delta XC^{L}_{f,t-1}$	-0.379	-0.858	-0.119	-0.800
	(0.514)	(0.684)	(0.548)	(0.696)
1st stage F-statistics	138.1	137.8	136.8	131.3
N	5,916	5,916	5,916	5,916

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of pre-sample period patent applications (1995-2000) as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). Countries that are rich, large, distant, and with high regulatory quality at the same time are excluded. All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1991-1994) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Appendix 3.2 Long Difference

In this subsection, a long difference between 2001 and 2007 is employed to examine the impact of competition with China on South Korean firms' innovation as an alternative specification. To do so, the measures of export competition and import competition are constructed as

$$\Delta XC_{f,t} = \frac{X_{f,0}}{Y_{f,0}} \sum_{S} \frac{X_{i,0}^{KRtoS}}{\sum_{S'} X_{i,0}^{KRtoS'}} \Delta_g \frac{X_{i,t}^{CNtoS}}{M_{i,t}^{S}}, \tag{A2}$$

$$\Delta IC_{f,t} = \left(1 - \frac{X_{f,0}}{Y_{f,0}}\right) \times \Delta_g \frac{X_{i,t}^{CNtoKR}}{M_{i,t}^{KR}}, \tag{A3}$$

where Δ_g indicates the Davis-Haltiwanger growth rate between 2001 and 2007. Year 0 is 2000, the year before the sample period in line with the main analysis. Then, the Davis-Haltiwanger growth rate of the number of patent applications between 2001 and 2007 is regressed on these measures and control variables similar to equation (38) and (39) without year fixed effects. The Davis-Haltiwanger growth rate is also used for the $Xsize_{f,t}$ variable.

Table A6 reports the estimation results for the overall impact of competition with China. Although the number of observations is smaller, and the magnitude of coefficients is different from Table 3 due to the different empirical specification, the results are qualitatively unchanged. All export competition coefficients are positive and significant at the five percent level, meaning that export competition increases innovation again. In contrast, import competition coefficients do not show consistent and statistically significant results. Although it is positive and significant at the ten percent level in column (4), it becomes insignificant when the 2SLS estimation strategy is involved in column (5).

Table A6: Overall impact of competition with China on innovation

	OLS (1)	2SLS (2)	OLS (3)	OLS (4)	2SLS (5)
$\Delta IC_{f,t}$	0.124	0.127		0.142*	0.154
	(0.077)	(0.136)		(0.084)	(0.161)
$\Delta XC_{f,t}$			0.889**	0.952**	0.958**
			(0.371)	(0.377)	(0.382)
1st stage F-statistics		920.3			671.7
N	2,933	2,933	2,933	2,933	2,933

Notes: This table reports the estimated coefficients for equation (38) using the growth of patent applications between 2001 and 2007 as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. All models include 2-digit industry fixed effects, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Columns (3)-(5) include the growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Table A7 shows the heterogeneous impact of competition with China across firms with different productivity. In line with the main analysis results in Table 4, export competition increases innovation of high-productivity firms. The importance of export competition found in the overall impact maintains, and the response is driven by high-productivity firms in line with the theoretical prediction. All export competition coefficients associated with high-productivity firms are positive and significant at the one percent level. The main results remain qualitatively unchanged.

Table A7: Heterogeneous impact of competition with China on innovation

	OLS (1)	2SLS (2)	OLS (3)	OLS (4)	2SLS (5)
$\Delta IC_{f,t}$	0.133	0.090		0.134	0.089
	(0.082)	(0.144)		(0.087)	(0.165)
$\Delta IC_{f,t} \times High_f$	-0.050	0.191		0.069	0.403
	(0.128)	(0.218)		(0.139)	(0.259)
$\Delta XC_{f,t}$			0.566	0.597	0.469
			(0.392)	(0.402)	(0.416)
$\Delta XC_{f,t} \times High_f$			0.848***	0.925***	1.232***
			(0.319)	(0.345)	(0.399)
1st stage F-statistics		471.5			237.1
N	2,933	2,933	2,933	2,933	2,933

Notes: This table reports the estimated coefficients for equation (39) using the growth of patent applications between 2001 and 2007 as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. Firms with the top quartile productivity within the 2-digit industry in 2000 are classified as high-productivity firms. All models include 2-digit industry fixed effects, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Columns (3)-(5) include the lagged growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Turning to the heterogeneity by export destinations, the export competition measure is decomposed into competition in two groups of countries as in the main analysis, but using the Davis-Haltiwanger growth rate between 2001 and 2007. Then, the modified version of equation (42) is estimated using these measures without year fixed effects.

Table A8 shows the estimation results considering which country has a leadership in each export market. Similar to the main results, export competition in markets where Korea led China increases innovation, whereas export competition in markets where Korean firms are laggards does not have such an impact. All coefficients in the second row are positive and significant. The import competition coefficient in column (2) is positive and significant, but it becomes insignificant when the 2SLS strategy is employed as shown in column (3).[50]

[50]Here, an export market where imports from Korea exceeded 80 percent of imports from China as of

Table A8: Heterogeneous impact of competition with China by market leadership

	OLS	OLS	2SLS
	(1)	(2)	(3)
$\Delta IC_{f,t}$		0.146*	0.153
		(0.084)	(0.161)
$\Delta XC^{H}_{f,t}$	0.718*	0.790*	0.794*
	(0.413)	(0.416)	(0.421)
$\Delta XC^{L}_{f,t}$	-0.036	-0.047	-0.047
	(0.588)	(0.591)	(0.591)
1st stage F-statistics			668.4
N	2,933	2,933	2,933

Notes: This table reports the estimated coefficients for equation (42) using the growth of pre-sample period patent applications (1995-2000) as a dependent variable. Columns (1) and (2) report the OLS results, whereas column (3) reports the 2SLS results. Countries in group H are where Korean share of imports is larger than Chinese share. All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1991-1994) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Table A9 shows export competition in countries with higher income, larger size, and better regulatory quality increases innovation, whereas export competition in other countries and import competition do not have statistically significant impact on innovation. Here, in contrast to the main text, competition in geographically farther countries from Korea does not have a positive and significant impact on innovation. However, other factors, especially income, are not sensitive to the change in empirical specification.

2000 is defined as H, allowing greater flexibility. In the main text, 100 percent is used as a cutoff. However, markets where China led Korea by a slight margin could be understood as a tight race. They are included in group H in this analysis.

Table A9: Heterogeneous impact of competition with China by destination

	Income (1)	Size (2)	Distance (3)	Regulation (4)
$\Delta IC_{f,t}$	0.149	0.153	0.153	0.151
	(0.161)	(0.160)	(0.161)	(0.161)
$\Delta XC^{H}_{f,t}$	1.077**	0.919*	0.075	0.882*
	(0.465)	(0.486)	(0.668)	(0.451)
$\Delta XC^{L}_{f,t}$	-0.072	0.057	0.900	0.113
	(0.325)	(0.265)	(0.878)	(0.380)
1st stage F-statistics	665.2	669.8	673.8	673.4
N	2,933	2,933	2,933	2,933

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of patent applications between 2001 and 2007 as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). All models include 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Finally, Table A10 shows the estimation results after dropping export destinations that are rich, large, distant from Korea, and have solid regulatory quality. Consistent with the results in Table 7, export competition in countries with higher income is positive and significant at the five percent level as shown in Column (1). Indeed, this is the only statistically significant coefficients in this table, implying that the positive and significant impact of competition in larger countries, in better regulated countries might be driven by those dropped countries. Without including those countries, size, distance, and regulatory quality do not play an important role in how firms respond to competition in export destinations. However, even dropping those countries, competition in richer countries increases innovation, highlighting the relative importance of export destination's income again.

Table A10: Heterogeneity by destination for a subset of countries

	Income (1)	Size (2)	Distance (3)	Regulation (4)
$\Delta IC_{f,t}$	0.133	0.147	0.148	0.154
	(0.159)	(0.161)	(0.161)	(0.161)
$\Delta XC^{H}_{f,t}$	0.688**	0.423	0.665	0.599
	(0.286)	(0.357)	(0.535)	(0.444)
$\Delta XC^{L}_{f,t}$	0.071	0.016	0.080	0.142
	(0.181)	(0.229)	(0.505)	(0.454)
1st stage F-statistics	679.1	664.8	665.9	668.0
N	2,933	2,933	2,933	2,933

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of patent applications between 2001 and 2007 as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). Countries that are rich, large, distant, and with high regulatory quality at the same time are excluded. All models include 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Appendix 3.3 Quality Adjusted Innovation

Although the number of patent applications is widely used as a measure of innovation in the literature, it may not capture the quality of innovation precisely. In this regard, the growth of citation-weighted patent applications is used as an alternative dependent variable following the literature (Trajtenberg, 1990; Bloom and Van Reenen, 2002).

Table A11 shows the results of estimating the overall impact. Coefficients in column (5), the most preferred specification, show that the response of citation-weighted innovation to export competition is positive and significant, whereas the impact of import competition is estimated as insignificant. The magnitude is different, and the results are weaker than the main results when the quality of innovation is considered, the results deliver qualitatively similar message. The overall impact of export competition is positive, whereas that of import competition is statistically not different from zero.

Table A11: Overall impact of competition with China on quality adjusted innovation

	OLS (1)	2SLS (2)	OLS (3)	OLS (4)	2SLS (5)
$\Delta IC_{f,t}$	-0.012	0.007		-0.002	0.043
	(0.020)	(0.055)		(0.021)	(0.061)
$\Delta XC_{f,t}$			0.249	0.247	0.279*
			(0.155)	(0.156)	(0.161)
1st stage F-statistics		621.8			524.3
N	20,531	20,531	20,531	20,531	20,531

Notes: This table reports the estimated coefficients for equation (38) using the growth of citation-weighted patent applications as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. All models include year fixed effects, 2-digit industry fixed effects, age, and the pre-sample period (1998-2000) average wages, tangible assets, and citation-weighted patent applications (in logarithms). Columns (3)-(5) include the growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Table A12 shows the heterogeneous impact of competition with China across firms with different productivity on quality adjusted innovation. In line with the main analysis results in Table 4, export competition increases innovation of high-productivity firms. All export competition coefficients associated with high-productivity firms are positive and significant at the ten percent level, whereas those related to import competition are not statistically distinguishable from zero. The main results remain qualitatively unchanged.

Table A12: Heterogeneous impact of competition with China on quality adjusted innovation

	OLS (1)	2SLS (2)	OLS (3)	OLS (4)	2SLS (5)
$\Delta IC_{f,t}$	-0.011	-0.007		-0.008	0.016
	(0.021)	(0.057)		(0.022)	(0.062)
$\Delta IC_{f,t} \times High_f$	-0.001	0.071		0.029	0.147
	(0.049)	(0.093)		(0.049)	(0.102)
$\Delta XC_{f,t}$			0.120	0.111	0.115
			(0.169)	(0.171)	(0.176)
$\Delta XC_{f,t} \times High_f$			0.357**	0.380**	0.471**
			(0.179)	(0.182)	(0.194)
1st stage F-statistics		303.6			236.9
N	20,531	20,531	20,531	20,531	20,531

Notes: This table reports the estimated coefficients for equation (39) using the growth of citation-weighted patent applications as a dependent variable. Columns (1), (3), and (4) report the OLS results, whereas columns (2) and (5) report the 2SLS results. Firms with the top quartile productivity within the 2-digit industry in 2000 are classified as high-productivity firms. All models include year fixed effects, 2-digit industry fixed effects, age, and the pre-sample period (1998-2000) average wages, tangible assets, and citation-weighted patent applications (in logarithms). Columns (3)-(5) include the lagged growth of export market size as an additional control variable. Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Turning to the heterogeneity by export destinations, the export competition measure is decomposed into the sum of competition in two groups of countries as in the main analysis. Table A13 shows export competition in markets where Korea led China increases innovation, whereas export competition in other countries and import competition do not have statistically significant impact on innovation. Here, after incorporating the quality of innovation, the export competition coefficient of interest is positive and significant at the ten percent level only in column (3), the most preferred specification, similar to Table A11.

Table A13: Heterogeneous impact of competition by market leadership

	OLS (1)	OLS (2)	2SLS (3)
$\Delta IC_{f,t-1}$		-0.002	0.042
		(0.021)	(0.061)
$\Delta XC^{H}_{f,t-1}$	0.268	0.267	0.297*
	(0.169)	(0.170)	(0.173)
$\Delta XC^{L}_{f,t-1}$	0.166	0.164	0.204
	(0.312)	(0.313)	(0.319)
1st stage F-statistics			524.1
N	20,531	20,531	20,531

Notes: This table reports the estimated coefficients for equation (42) using the growth of citation-weighted patent applications as a dependent variable. Columns (1) and (2) report the OLS results, whereas column (3) reports the 2SLS results. Countries in group H are where Korean share of imports is larger than Chinese share. All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and citation-weighted patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Table A14 shows export competition in countries with higher income, larger size, and greater distance from Korea increases innovation, whereas export competition in other countries and import competition do not have statistically significant impact on innovation. Here, competition in countries with better regulatory quality does not have a positive and significant impact on innovation unlike the main analysis. However, other factors, especially income, are not sensitive to the change in the dependent variable.

Table A14: Heterogeneous impact of competition with China on quality adjusted innovation by destination

	Income	Size	Distance	Regulation
	(1)	(2)	(3)	(4)
$\Delta IC_{f,t}$	0.043	0.040	0.046	0.040
	(0.061)	(0.061)	(0.061)	(0.061)
$\Delta XC^{H}_{f,t}$	0.356*	0.306*	1.692***	0.275
	(0.210)	(0.180)	(0.601)	(0.197)
$\Delta XC^{L}_{f,t}$	0.113	1.470	-0.102	0.567
	(0.541)	(1.071)	(0.220)	(0.607)
1st stage F-statistics	517.9	526.5	523.1	518.5
N	20,531	20,531	20,531	20,531

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of citation-weighted patent applications as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and citation-weighted patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.

Finally, Table A15 shows the estimation results after dropping export destinations that are rich, large, distant from Korea, and have solid regulatory quality. Consistent with the results in Table 7 and all other results from different empirical specifications in this Section, export competition in countries with higher income is positive and significant as shown in Column (1). Again, this is the only statistically significant coefficient. While results from categorizing countries based on their size, distance from Korea, and regulatory quality are sensitive to empirical specifications and the choice of dependent variable, the positive and significant impact of export competition in richer countries remains robust to potential concerns.

Table A15: Heterogeneous impact on quality adjusted innovation by destination for a subset of countries

	Income (1)	Size (2)	Distance (3)	Regulation (4)
$\Delta IC_{f,t}$	0.028	0.029	0.032	0.031
	(0.059)	(0.059)	(0.060)	(0.061)
$\Delta XC^{H}_{f,t}$	4.574**	0.488	1.006	0.260
	(2.244)	(0.573)	(0.974)	(0.508)
$\Delta XC^{L}_{f,t}$	-1.167	0.172	0.247	0.621
	(1.520)	(1.449)	(0.451)	(0.625)
1st stage F-statistics	546.2	546.8	543.3	527.4
N	20,531	20,531	20,531	20,531

Notes: This table reports the 2SLS coefficients for equation (42) using the growth of citation-weighted patent applications as a dependent variable. Countries in group H are those with above-median GDP per capita in column (1), countries with above-median GDP in column (2), countries with above-median distance from Korea in column (3), and countries with higher regulatory quality in column (4). Countries that are rich, large, distant, and with high regulatory quality at the same time are excluded. All models include year fixed effects, 2-digit industry fixed effects, the lagged growth of export market size, age, and the pre-sample period (1998-2000) average wages, tangible assets, and citation-weighted patent applications (in logarithms). Standard errors in parentheses are clustered at the firm level. The first stage F statistics refers to Kleibergen-Paap F-statistics. Sample includes manufacturing firms with at least one patent application between 2001 and 2007. ***, **, and * indicate 0.01, 0.05, and 0.1 significance level, respectively.