Inter-Regional Tech Complementarity: A Mechanism for Balanced Development and GVC Upgrading

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Abstract: *In the complex architecture of global value-chain (GVC) trade, firms' technological content increasingly reflects external knowledge flows. This study examines how inter-regional technological complementarity shapes firms' GVC advancement, measured by the domestic value-added rate (DVAR) in exports. Using integrated Chinese microdata (2000-2014), we find this complementarity significantly boosts export DVAR, explaining about one-quarter of its observed growth. Two mechanisms drive this effect: increased use of domestic intermediates and gains in firm productivity. The benefits are especially large for firms with lower human capital and for those in accessible, innovation-peripheral regions, helping narrow productivity gaps across firms and space. Affected firms also exhibit broader export scopes, higher product quality, more diversified destinations, and greater markups—firm-level evidence of GVC upgrading. These findings highlight how external technological linkages drive upgrading and underscore the importance of fostering inter-regional synergies for balanced development.*

Keywords: *technological complementarity; global value chains; domestic value-added rate (DVAR); balanced regional development*

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1. Introduction

The *Report to the 20th National Congress of the Communist Party of China* in 2022 unveiled the strategic priorities for China's new development paradigm. First, it requires strengthening the endogenous momentum and resilience of China's domestic economic circulation. Second, it calls for enhancing the quality and sophistication of international economic circulation. Central to this strategy is the explicit mandate to advance urban-rural integration and coordinated regional

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development. Thus, achieving balanced regional development is not just a domestic policy goal but also a fundamental prerequisite for elevating China's standing in GVCs and realizing higher-quality growth. Traditional comparative advantage theory holds that each region should specialize in and export goods that align with its natural production strengths (Costinot, 2009; Antràs et al., 2024). This principle has long guided China's growth path. China's eastern coastal areas focus on the low- and mid-tier links of GVCs, gaining cost competitiveness by drawing raw materials, labor, and other inputs from the central and western regions. However, this lopsided division of labor neglected regional coordination, hampered the climb of domestic firms up GVCs, and exacerbated income gaps between inland and coastal areas (Fan, 2004; Tombe & Zhu, 2019).

This paper proposes a new perspective for understanding the relationship between trade and coordinated regional development—one centered on inter-regional technological complementarity within the same industry. Over the past four decades, China has accumulated substantial innovation resources and capabilities across various regions. As technologies have become more sophisticated and specialized, innovative activity has increasingly diffused beyond core hubs into peripheral regions, giving rise to growing technological complementarities across regions (Zheng et al., 2023)[1]. Meanwhile, global production has grown increasingly fragmented: tasks, components, and technologies are dispersed across locations with particular strengths (Antràs et al., 2024). This trend provides an essential technological foundation for various regions across China to coordinate their domestic division of labor through complementarity rather than competition[2]. As technological complementarity strengthens within the same industry, firms in one region benefit from positive technological externalities generated by other areas. Access to complementary technologies and intermediate inputs enhances firms' production capabilities and improves their comparative advantage (Boehm et al., 2022). This occurs through two main channels: First, firms in other regions may pioneer innovations closely related to local industries. Through processes of adaptation, recombination, and incremental improvement, local firms can absorb these innovations and incorporate them into their own technological base—reducing operational costs and boosting productivity (Zheng et al., 2023). Second, because modern products embody bundles of interlinked technologies, greater technological complementarity improves the compatibility between various regions' outputs—ranging from basic materials to sophisticated intermediates and advanced manufacturing equipment—and the needs of local producers. This encourages firms to source more intermediate inputs domestically, increasing the domestic value-added content of exports (Kee & Tang, 2016). Such complementarity not only enhances firms' global competitiveness but also reshapes the pattern of regional participation in international trade, enabling more localities and more firms to take part. Seen from this perspective, coordinated regional development does not emerge from competition over similar factors or identical production roles. Instead, it arises from differentiated yet complementary technological capabilities that collectively generate

[1] For simplicity, we refer to inter-regional technological complementarity within the same industry as "technological complementarity" or "inter-regional technological complementarity."

[2] Indeed, China's domestic market has already become more integrated; for example, the share of inter-provincial trade outflows in total national trade outflows rose from 15.3% to 21.4% between 2000 and 2014, illustrating deeper internal specialization (Li et al., 2022).

external economies and a more substantial national comparative advantage. By embedding a more diverse set of regions into the international production network, inter-regional technological complementarity provides a powerful mechanism for achieving shared growth and a more balanced, mutually reinforcing pattern of regional development in China.

This paper develops a theoretical model of intermediate input sourcing. It empirically tests its implications using an unusually rich micro-dataset that merges the Chinese Industrial Enterprise Database, the China Customs Database, and invention patent application records from the China National Intellectual Property Administration (CNIPA) for the years 2000-2014. Our analysis centers on the export DVAR—the share of a firm's export value generated domestically—as the key micro-level indicator of firms' upgrading within GVCs. An increase in DVAR generally indicates that firms are sourcing a greater share of their intermediate inputs from within China. Such deepened domestic sourcing reduces reliance on imported intermediates, enables firms to capture a larger share of value-added in international markets, and reflects more efficient resource allocation and enhanced competitiveness under globalization (Zheng & Zheng, 2020). To quantify inter-regional, intra-industry technological complementarity, we construct an index that extends the seminal framework of Jaffe (1986) and builds on the refinements proposed by Zheng et al. (2023). Using detailed patent data—including application year, prefecture-level location, and International Patent Classification (IPC) codes—we measure the degree of technological proximity and complementarity across regions within the same industry. Anchored in this theoretical model and supported by high-resolution microdata, the paper provides rigorous evidence that technological complementarity among areas operating in the same sector significantly facilitates Chinese firms' ascent within GVCs.

This study makes three major contributions. (1) Providing a new perspective on inter-regional complementarity and identifying a mechanism for GVC upgrading via domestic intermediate-product innovation. Existing research typically explains regional complementarity through regional integration (Faber, 2014; Fan & Zhou, 2022), industrial specialization and relocation (Coşar et al., 2016; Lu et al., 2023), or the construction of a unified national market (Liu & Kong, 2021; Li et al., 2022). These studies argue that reducing inter-regional market segmentation and facilitating cross-regional investment help optimize the regional industrial division of labor. However, far fewer studies examine how technological linkages across regions generate complementarity, nor do they quantify the economic returns from such linkages. This paper fills that gap. We show that intra-industry technological complementarity across regions significantly promotes firms' upgrading in GVCs, and that this effect remains strong for one to five years. Instrumental variable estimates indicate that rising inter-regional technological complementarity accounts for roughly 25 percent of the total increase in Chinese firms' export DVAR from 2000 to 2014—evidence of substantial economic significance. Moreover, these technological links create fertile ground for domestic intermediate-product innovation. We find that stronger technological complementarity facilitates the development of innovative intermediate inputs, enabling firms to expand their export product range, improve product quality, enter more destination markets, and command higher markups. These patterns are hallmark indicators of GVC upgrading. The findings not only substantiate the pathway for emerging economies to achieve GVC upgrading through innovation in intermediate products, but also offer an economic rationale rooted in technological complementarity that is essential for analyzing the contemporary strategic reconfigurations of global production, including the emerging phenomena of "friend-shoring" and "near-shoring." (2) Expanding the understanding of the sources of firm and regional comparative advantage. Conventional wisdom traces firms' comparative advantage to the availability of high-quality inputs and internal innovation capacity (Boehm et al., 2022). Accordingly, the literature has focused overwhelmingly on how firms can enhance their own R&D capabilities (Yu et al., 2016; Alfaro-Ureña et al., 2022; Aghion et al., 2024). However, this firm-centric view overlooks the external and inter-regional sources of innovation and underexplains why firms in different regions face systematically different opportunities. Our study introduces the perspective of inter-regional technological complementarity to fill this conceptual gap. We find that higher levels of intra-industry complementarity significantly increase firms' access to domestic intermediate inputs and complementary technological knowledge. This expanded technological and input base, in turn, raises firms' domestic input shares, boosts TFP, and enhances innovation efficiency. These findings enrich current understandings of the origins of comparative advantage and highlight why otherwise similar firms exhibit persistent performance differences depending on their regional technological environment. (3) Demonstrating the role of technological externalities in China's distinct development path and linking them to balanced regional growth. Recent research on the United States documents a steady decline in inter-regional knowledge diffusion and a widening dispersion of firm productivity (Andrews et al., 2016; Akcigit & Ates, 2023). China presents a contrasting pattern: disparities in DVAR across regions and among firms within industries have steadily narrowed over time.[3] We explain this divergence through the lens of China's inter-regional technological complementarity. Higher levels of complementarity increase local technological availability and broaden the range of domestic intermediate inputs accessible to firms. This mechanism disproportionately benefits firms in innovation-peripheral regions and those with lower human capital—groups most in need of support. As a result, technological complementarity reduces inter-regional and inter-firm disparities in DVAR and fosters more balanced regional development. The broader policy implication is clear: China should capitalize on its distinctive comparative advantages—its extensive regional innovation resources, comprehensive industrial structure, and vast potential for technological interactions. By intentionally deepening inter-regional technological complementarity, China can promote technological cooperation, accelerate productivity convergence, enhance national competitiveness, and advance its collective ascent in GVCs.

2. Data and Stylized Facts

2.1 Data Sources

The empirical analysis rests on three matched micro-datasets spanning 2000-2014: (1) China Customs Trade Statistics (General Administration of Customs): Firm-product-level import and

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[3] While DVAR and TFP describe distinct dimensions of firm performance, the existing literature widely posits a high degree of correlation between these two indicators (Shao & Su, 2019; Sheng & Wang, 2022).

export records for the universe of Chinese trading firms, including firm identifiers, 6-digit HS codes, quantities, values, trade regimes (processing vs. ordinary), and destination/origin countries. To ensure consistency across multiple HS revisions during the sample period[4], all records are harmonized to the HS1996 classification using official UN correspondence tables. Chinese Industrial Enterprise Database (National Bureau of Statistics): Annual survey data covering all state-owned firms and all private firms above a certain revenue threshold, with detailed balance-sheet, income-statement, employment, and ownership information.[5] The customs and industrial enterprise datasets are merged using the sequential matching algorithm of Brandt et al. (2012). Patent Database (China National Intellectual Property Administration): The complete registry of patent applications since 1985, containing application date, applicant name and address, patent title, type (invention, utility model, design), and full International Patent Classification (IPC) codes. Following Kou & Liu (2020), we link these patents to firms in the industrial enterprise database and extract the fine-grained IPC information to construct our measure of inter-regional technological complementarity.

2.2 Key Variable Construction

2.2.1 Technological complementarity

We build on the technological proximity framework pioneered by Jaffe (1986) and later adapted by Bloom et al. (2013) to capture technological spillovers. However, technological similarity conflates two distinct forces (Zheng, 2023): competition—when regions specialize in the same narrowly defined technological area—and complementarity—when they specialize in different but related areas within the same broader technological domain. For example, when two regions concentrate their patents in the same 3-digit IPC subclass, they are likely to produce similar products and therefore exhibit a competitive rather than a complementary relationship. In contrast, when two regions specialize in different 3-digit IPC subclasses within the same broader technological class, they engage in distinct but related technological activities. Although their main fields do not overlap, their shared conceptual frameworks and compatible knowledge bases allow them to benefit from each other's technological resources, thereby generating technological complementarity. By comparison, technologies belonging to entirely different major IPC classes are generally unrelated and cannot be combined in the same R&D or production process. Based on this reasoning, technological complementarity can be expressed as the similarity between regions in broader technological classes minus the similarity arising within the same subclasses.

$$Cra_{jJk} = \frac{\vec{T}^{g}_{jk} \times \vec{T}^{g}_{Jk} - \vec{T}^{m}_{jk} \times \vec{T}^{m}_{Jk}}{\sqrt{|\vec{T}^{g}_{jk}||\vec{T}^{g}_{Jk}|}} \tag{1}$$

where j and J are indices representing the regions; k represents the industry; g and m represent

[4] The commodity classification standard used by China Customs varied during the sample period: HS96 was utilized before 2002, followed by HS02 (2002-2006), HS07 (2007-2011), and HS12 (2012-2014).

[5] Given the severe data quality issues observed in the 2010 sample, we follow the methodology of Kou & Liu (2020) and exclude the 2010 observations from the analysis.

the major technological class and technological subclass, respectively, and $\vec{T}$ describes the regional technology distribution, defined as a one-dimensional vector composed of the patent counts for each technology. $|\vec{T}|$ is the Euclidean distance of vector $\vec{T}$. $\vec{T}_g=[N_1,...,N_G]$, G is the total number of major technological class categories; $\vec{T}_m=[N_1,...,N_M]$, and M is the total number of technological subclass categories.

Finally, we further weighed Cra_{jJk} to obtain a region-industry-level measure of complementarity with all other regions. A region may exhibit similar complementarity values with multiple different regions. However, the actual economic effect of each linkage can differ depending on the partner region's knowledge stock. To account for this, each term is weighted by the region's share of invention patent applications in the industry relative to the national total.

$$C_{jk}=\sum_{j=1}^{N}\frac{Patent_{Jk}}{\sum_{j=1}^{N}Patent_{Jk}}Cra_{jJk} \tag{2}$$

2.2.2 Firm-level export DVAR

The export DVAR reflects the share of a firm's export value produced domestically. Notably, it captures the firm's relative importance as both a demander and supplier of domestic intermediate inputs and serves as an essential indicator of its position in the GVC (Zhang et al., 2013; Lü et al., 2023). Compared with measures based on upstream or downstream positions in the international division of labor, DVAR is more helpful in understanding the actual gains a country obtains from participation in global trade (Zheng & Zheng, 2020). In this paper, the DVAR is measured as follows:

$$DVAR_{it}=\frac{Y_{it1}}{Y_{it}}\left(1-\frac{IMP_{it1}+\delta_{it1}^{F}}{Y_{it1}}\right)+\frac{Y_{it2}}{Y_{it}}\left(1-\frac{IMP_{it2}-\delta_{it2}^{K}+\delta_{it2}^{F}}{Y_{it2}}\right) \tag{3}$$

For trade-regime distinctions, subscripts 1 and 2 denote pure processing trade and ordinary trade, respectively. Y_{it} and IMP_{it} denote firm i's total export value and total import value in year t, respectively. For firms engaged in both regimes, we calculate processing trade exports and ordinary trade exports separately. It is important to note that products imported under processing trade must be re-exported and cannot be sold domestically; therefore, they serve entirely as inputs for processing trade exports. By contrast, products imported under ordinary trade can either be exported or sold domestically. Accordingly, following Kee & Tang (2016), the imported inputs associated with ordinary trade exports are scaled by the ratio of the ordinary trade export value to total output. δ_{it2}^{K} represents the value of imported capital goods. In addition to conventional intermediate inputs, firms import machinery and other capital goods necessary to build or enhance productive capacity rather than for direct production. These capital goods are excluded from the calculation of imported inputs. For processing trade, capital goods are generally recorded separately in customs data. For ordinary trade, the value of imported capital goods is determined by classifying imported products into consumption, intermediate, and capital goods under the Broad Economic Categories (BEC Rev. 4) system. δ_{it2}^{F} denotes the share of foreign value embedded in domestically sourced intermediate inputs used in export production. Following Zhang et al. (2013), this share is conservatively set at 5%. Finally, adjustments are made to account for trade intermediaries, indirect imports, and other factors that could otherwise introduce measurement errors in DVAR estimates, following the approach of Lü et al. (2023).

2.3 Stylized Facts

Stylized fact 1: from concentration to dispersion – the emergence of inter-regional technological complementarity

China's manufacturing geography has long exhibited a classic core-periphery structure, centered on export-oriented industrial clusters. Coastal cities, benefiting from deep-water ports, favorable geography, policy support, and continuously improving business environments, became the preferred destinations for both foreign investors and domestic firms. During this period, these coastal regions concentrated key production factors—capital, skilled labor, and advanced technologies—emerging as national hubs of manufacturing and technological innovation. Inland areas, lacking comparable industrial infrastructure, location advantages, and policy support, experienced relatively slower economic development.

However, unbalanced regional development eventually created constraints. Consequently, it developed coastal areas, and the supply of land, talent, and other factors available for production and R&D became limited, driving up factor prices. At the same time, competition in local product markets intensified as new firms entered, eroding average profit margins and sometimes bringing them to zero. Rising factor costs compelled firms to consider investing in other regions where factor prices were lower. Simultaneously, technological development became increasingly complex and diversified. The competitive advantage of concentrating production and R&D in a single city began to diminish. Peripheral regions, with existing technical foundations, ample land, and lower-cost production factors, became attractive locations for relocated manufacturing bases and R&D centers[6]. As a result, upstream and downstream firms within the same industry began to disperse geographically. Production capacities and technological capabilities, once concentrated in a few coastal regions, gradually spread across multiple regions. Thus, this evolution fostered inter-regional technological complementarity. The economic manifestation of this shift is evident in growing cross-regional collaboration in both production and technology development, with firms increasingly relying on technological inputs from multiple locations. To document this trend, we calculate Herfindahl-Hirschman Indices (HHI) for manufacturing output and patent activity at the prefecture-level city, disaggregated by technology intensity[7]. Figures 1 and 2 show that across all technology levels, output concentration initially increased, peaked around 2003, and then steadily declined, consistent with the concentration-to-dispersion dynamic described above. Patent concentration data reveal a similar story: in high-tech industries, patent HHIs have declined nearly continuously since 2000; in medium-high, medium-low, and low-tech sectors, HHIs initially rose and later fell. This pattern reflects the

[6] These strategies include, but are not limited to, the Great Western Development, Rise of Central China, Revitalization of the Northeast, and Yangtze River Delta Integration, all launched by the central government during this period to foster industrial interaction and achieve balanced inter-regional development across China's coastal and inland economic geography.

[7] Herfindahl-Hirschman Index calculation formula is: $HHI=\sum_{i=1}^{n}(y_i^j/y^j)^2$, among which, y_i^j represents city i industry j's current year output value, and y^j represents China industry j's total output value.

growing inability of any single region to support the full range of technological knowledge needed for increasingly sophisticated products. Within the same industry, the technological base is now increasingly composed of complementary contributions from multiple regions—a phenomenon most evident in high-tech sectors.

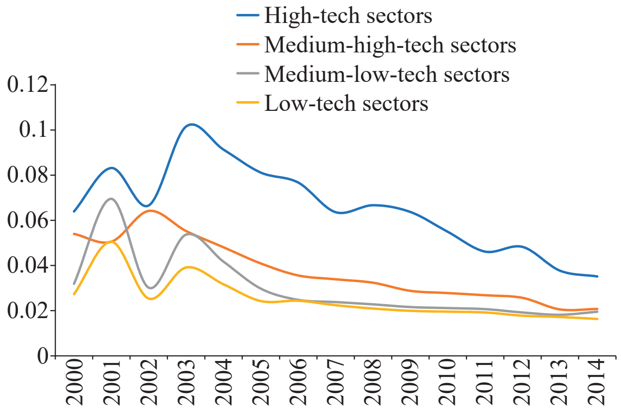

Fig. 1. Change in regional output HHI across technology industries

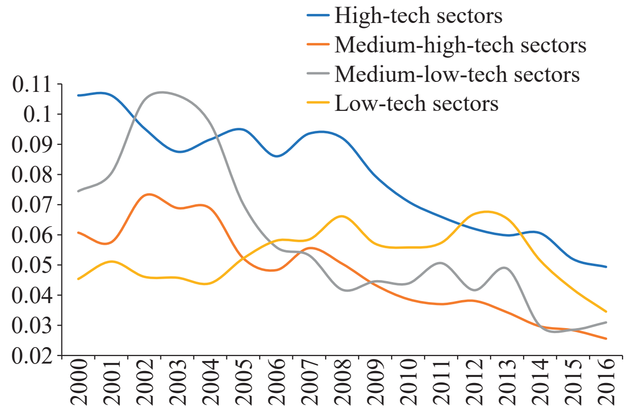

Fig. 2. Regional patent HHI by technology intensity

To verify the mechanism behind this pattern, we examined cross-industry differences in technological complementarity. Since high-tech industries operate with far greater complexity—requiring more sophisticated know-how in product design, R&D, and production processes—they are structurally more dependent on external technological inputs. This makes them more likely to leverage public knowledge originating from other regions to support local production. To test this idea, we compute the average level of inter-regional technological complementarity for each industry in 2014, the final year of our sample. Table 1 reports the four industries with the highest and lowest complementarity scores. The contrast is sharp: industries with the strongest complementarities are classic high-tech sectors such as instrumentation and meters, special-purpose machinery, computers and electronics, and pharmaceuticals. At the other end of the spectrum lie traditional medium- and low-tech industries, including leather and footwear, fur and feather products, textiles, and furniture.[8] We further calculate each industry's CR_4 index[9] of technological complementarity—defined as the share of the four leading cities' complementarity relative to the national total—to capture differences in geographic concentration. The results also reveal a clear pattern: technological complementarity in high-tech industries is much more geographically dispersed, whereas complementarity in medium- and low-tech industries remains tightly concentrated in only a few locations. Taken together, these findings indicate that high-tech industries form broader and deeper inter-regional complementary relationships, both in scope and

[8] Pharmaceutical manufacturing, despite being highly R&D-intensive, shows weaker complementarity at the national level simply because its production is geographically concentrated in only a handful of regions.

[9] $CR_4=\sum_{i=1}^{4}C_{ik}/\sum_{i=1}^{n}C_{ik}$, where C_{ik} is the technical complementarity index between industry k in region i and industry k in all other regions; $\sum_{i=1}^{4}C_{ik}$ denotes the sum of the technical complementarity levels of industry k for the four highest-ranking cities nationwide; and $\sum_{i=1}^{n}C_{ik}$ represents the aggregate technical complementarity of industry k across all domestic prefecture-level cities.

intensity. In contrast, technological complementarity in lower-tech industries is limited to a small number of regions and remains comparatively weak.

TABLE 1. Industry characteristics of inter-regional technical complementarity

High-complementarity industries	Average	Low-complementarity industries	Average	Low concentration industries	CR_4	High concentration industries	CR_4
Hnstrumentation manufacturing	0.61	Leather, furs, feathers, and related products and footwear manufacturing	0.01	Special equipment manufacturing	0.01	Leather, furs, feathers, and related products and footwear manufacturing	0.31
Electrical machinery and equipment manufacturing	0.48	Non-metallic mineral products	0.04	Motor vehicle manufacturing	0.02	Chemical fiber manufacturing	0.11
Motor vehicle manufacturing	0.48	Chemical fiber manufacturing	0.04	Instrumentation manufacturing	0.02	Paper and paper products	0.06
Special equipment manufacturing	0.47	Pharmaceutical manufacturing	0.07	Electrical machinery and equipment manufacturing	0.02	Textile, garment, and apparel manufacturing	0.06

The geographic dispersion of production and technology within the same industry expands the opportunities for local firms to build capacity-sharing partnerships with firms in other regions and to absorb external technological knowledge. This process generates inter-regional, industry-level technological complementarities that create substantial positive externalities for local enterprises. While extensive research has examined how local innovative capacity and industrial clusters shape firm performance, the multi-regional evolution of technology has made cross-regional technological complementarity increasingly vital. However, this perspective remains relatively underdeveloped in discussions of firms' sources of comparative advantage. In this paper, we define inter-regional technological complementarity as the degree to which external technological sources are functionally compatible with a region's own technological base. Greater complementarity implies that firms can incorporate a broader range of relevant non-local technologies and complementary intermediate inputs into their production processes.

Stylized fact 2: Inter-regional technological complementarity is strongly associated with firms' export domestic value-added

Although our measure of technological complementarity draws on patent application data from the same industry across different regions, it is essential to note that any single firm's R&D accounts for only a negligible share of local innovation. No individual enterprise can meaningfully influence the overall scale or direction of another region's patenting activity. Consequently, inter-regional technological complementarity is determined not by a firm's own R&D or export behavior, but by the collective innovation efforts of all actors in the regional system. These include universities, research institutes, and the broader population of firms. From this standpoint, technological complementarity is effectively exogenous to any given firm.

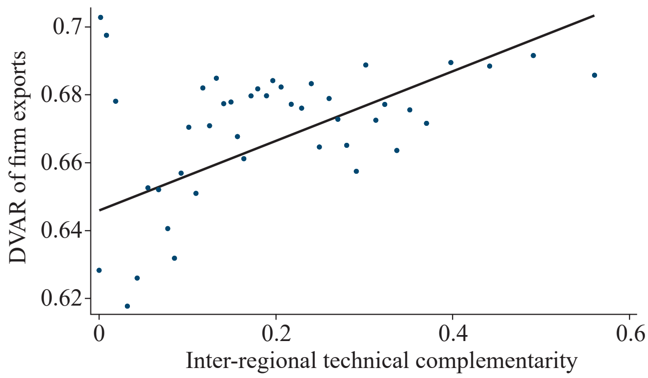

Fig. 3. Regression scatter diagram

Figure 3 plots the regression relationship between inter-regional technological complementarity and the DVAR of firm exports. The scatter plot reveals a clear positive association: firms located in regions with higher technological complementarity tend to exhibit higher export DVAR. This empirical pattern is consistent with the mechanisms outlined above. When inter-regional complementarity is present, local firms benefit through two main channels: First, enhanced access to complementary external public technical knowledge. Higher technological complementarity expands the pool of external, industry-relevant knowledge available to firms. As such, this facilitates more effective R&D activity and enables firms to boost productivity by adopting new technologies and equipment originating from the same industry innovators in other regions. Second, a clearer, more synergistic inter-regional division of labor along industrial and supply chains. Stronger complementarity increases the availability of upstream intermediate inputs—both production-related and innovation-related—produced or developed in other regions. These inputs align more closely with local production needs, raising the share of domestic intermediate goods used by exporting firms and directly increasing their export DVAR. To illustrate these mechanisms, we classify cities into high-complementarity and low-complementarity groups based on each city's mean level of technological complementarity. For each group of firms, we compute the average TFP and the share of domestic intermediate inputs, and report the results in Table 2. The differences are striking: firms in high-complementarity cities exhibit significantly higher TFP and a substantially greater reliance on domestic intermediates than those in low-complementarity cities.

TABLE 2. Firm performance differences across cities with high vs. low technological complementarity

Variable	Cities with high technological complementarity		Cities with low technological complementarity		Mean differential
	Sample size	Mean	Sample size	Mean	
TFP	203129	1.96	202364	1.79	0.17***
Share of domestic intermediate input utilization	203129	0.57	202364	0.56	0.01***

Stylized fact 3: technological complementarity narrows inter-regional gaps in firms' export DVAR

Studies based on US data show a persistent and troubling pattern over the past two decades: the gaps between frontier and laggard firms—in productivity, patenting, and output—have continued to widen (Andrews et al., 2016; Akcigit & Ates, 2023). This divergence dampens firms' innovative dynamism and ultimately undermines aggregate economic growth. A principal explanation is the decline in knowledge diffusion both across regions and within industries (Akcigit & Ates, 2023). Since such diffusion is patent-driven mainly, it is directly connected to the notion of inter-regional technological complementarity emphasized in this paper. Against this backdrop, we examined whether China exhibits a similar divergence and whether rising technological complementarity can counteract it. Figure 4 presents two striking trends over the sample period: Inter-regional technological complementarity rises steadily year by year. The dispersion of firms' export DVAR—measured by the Theil index—declines consistently. The movements of the two series display a significant negative correlation, suggesting that stronger technological complementarity is associated with a narrowing of inter-regional gaps in firm performance. Further regional evidence, shown in Figure 5, reinforces this pattern. Peripheral cities have experienced faster growth in technological complementarity, gradually closing their gap with China's innovation centers. Correspondingly, the DVAR gap[10] between firms in peripheral and core cities has narrowed along a remarkably similar trajectory, tracking changes in complementarity. This form of regional catch-up, driven by rising technological complementarity and reflected in firms' domestic value-added performance, remains largely overlooked in the existing literature. The sections that follow offer a deeper exploration of its mechanisms and implications.

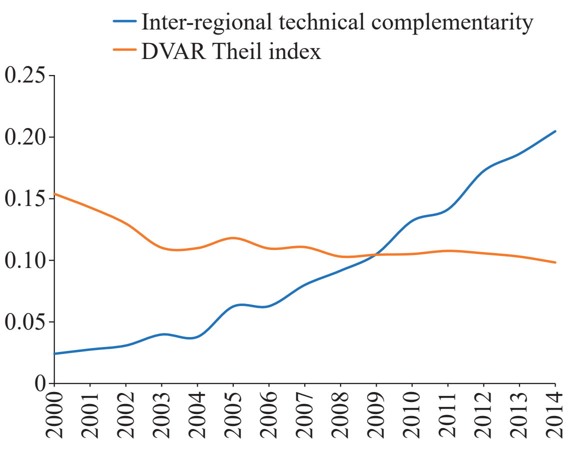

Fig. 4. Inter-regional technical complementarity and the Theil index of firm DVAR dispersion

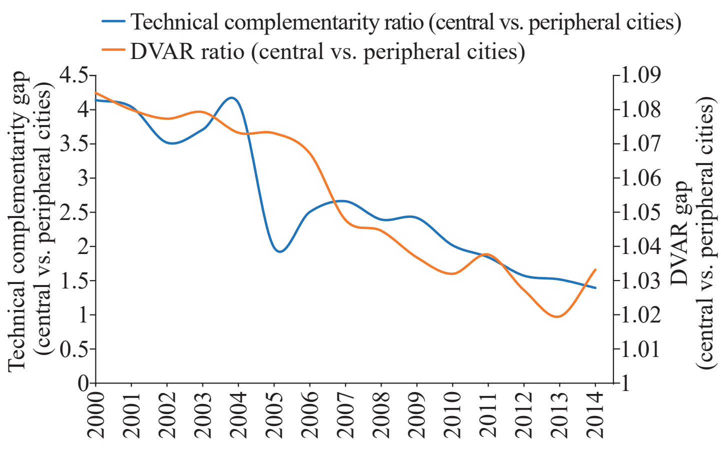

Fig. 5. Technical complementarity and DVAR gaps between central and peripheral cities

[10] In defining innovation centers, we follow Zheng et al. (2023), identifying the top twenty cities in terms of domestic technological sophistication—Beijing, Shanghai, Shenzhen, Guangzhou, Suzhou, Chengdu, Hangzhou, Tianjin, Xi'an, Nanjing, Wuhan, Ningbo, Wuxi, Harbin, Changsha, Shenyang, Dalian, Qingdao, Foshan, and Changzhou—with all other prefecture-level cities classified as peripheral. Using provincial capitals as an alternative definition yields the same conclusion.

3. Theoretical Model and Hypotheses

To clarify the effect of inter-regional technological complementarity on firms' export DVAR and its possible mechanisms, we developed a sourcing model for exporting firms. In this framework, exporters differ in the degree of technological complementarity between their local industry and the same industry in other domestic regions. Firms make production and input-sourcing decisions conditional on their TFP, generating heterogeneous export DVAR outcomes.

3.1 Final Demand

Following Rodriguez-Lopez (2011), foreign consumers' preferences over a continuum of differentiated final products are represented by a translog expenditure function:

$$\ln E=\ln U+a+\frac{1}{N}\int_{i\in\omega}\ln p_i di+\frac{\gamma}{2N}\int_{i\in\omega}\int_{j\in\omega}\ln p_{it}(\ln p_j-\ln p_i)djdi \tag{4}$$

Here: E is the minimum expenditure required for a representative consumer to achieve utility U. N is the number of heterogeneous final products available to the foreign consumer. p_i is the price of the final product $i\in\omega$ in the set of available products omega. $a=\frac{1}{2\gamma N}$, with γ greater than zero; higher γ indicates stronger substitutability between products. a is a decreasing function of N, implying that when all product prices are equal, the expenditure needed to reach a given utility using a single product decreases as product variety N increases. Notably, this captures the love-of-variety effect inherent in translog preferences.

For a given income level E and the expenditure function in Equation (4), applying Shephard's Lemma yields the consumer demand for a specific heterogeneous final product i:

$$q_i=\gamma\left(\ln\frac{\hat{p}}{p_i}\right)\frac{E}{p_i} \tag{5}$$

where $\hat{p}=e^{\frac{1}{N\gamma}+\overline{\ln p}}$ is the maximum price a firm can charge, $\overline{\ln p}=\frac{1}{N}\int_{i\in\omega}\ln p_j dj$.

3.2 Final Product Production

The production function of the representative enterprise is:

$$Y_i=\emptyset_i(\varphi)K_i^{a_K}L_i^{a_L}M_i^{a_M},\ a_K+a_L+a_M=1 \tag{6}$$

Let Y_i, $\emptyset_i$, K_i, L_i and M_i denote firm i's output, TFP, capital, labor, and intermediate inputs, respectively. The parameters a_K, a_L and a_M represent the output elasticities of capital, labor, and intermediate inputs. Firms operate in a monopolistically competitive market[11]. Each firm produces a final good by adapting and assembling a continuum of intermediate inputs sourced from both domestic and foreign locations. Intermediate inputs span the closed interval [0,1]; each point in the interval corresponds to one variety, and the usage density for every variety v is normalized to 1. Different varieties are imperfect substitutes with an elasticity of substitution $\lambda>1$. This setup follows Halpern et al. (2015). The aggregate price index of intermediate inputs, P_M, is therefore given by:

$$P_M(\varphi)\&=\left(\int_0^1 z_i(\varphi,v)^{1-\lambda}dv\right)^{\frac{1}{1-\lambda}} \tag{7}$$

[11] This market structure implicitly assumes that industry characteristics are not determined by a single dominant firm—an assumption that is appropriate in this context, as even within narrowly defined product categories, firms from different regions produce and export similar goods while serving the same global market.

Firm productivity, denoted by $\emptyset_i(\varphi)$, depends on the firm's level of innovation—specifically, the invention technologies embodied in its production process. These technologies may arise from in-house R&D or be acquired from outside the firm. A higher degree of technological complementarity, φ between the firm's local industry and the same industry in other regions means that different areas possess a larger stock of closely related technologies and key production equipment that local firms can use. By drawing on this complementary external public knowledge, firms can raise their productivity. Moreover, because firms are located in regions with different levels of technological complementarity, their productivity levels differ accordingly. Higher-productivity firms can produce more final output using the same quantity of intermediate inputs. Thus, a firm's marginal cost is a decreasing function of both its productivity and the degree of technological complementarity. Without loss of generality, let $\emptyset_i(\varphi)=A_i e^{\varphi}$.

Let $z_i(\varphi,v)$ denote the firm's procurement cost for intermediate variety v[12]. Because each intermediate variety v is used with unit density, $z_i(\varphi,v)$ also represents the unit price of intermediate v. Differences in regional technological complementarity, together with frictions in matching intermediate inputs to firms'production, generate heterogeneity in intermediate input prices across firms. On one hand, the prices firms face for domestic or foreign intermediates are influenced by the degree of technological complementarity. When regions exhibit stronger complementarity, there are more firms in the other areas engaged in R&D and production of upstream or downstream technologies and products closely related to the local industry. Competition in intermediate input markets is therefore more intense, and procurement prices are correspondingly lower. On the other hand, even after observing the domestic and foreign prices of a given intermediate, firms face an adjustment-cost shock drawn from a Frechet distribution with shape parameter θ. This shock represents the unexpected cost of adapting the intermediate input to the production process. As a result, firms with the same production capability may nonetheless select different sourcing regions for the same variety.

Given these sourcing conditions, an exporting firm chooses the region—domestic or foreign—that provides the lowest cost for each intermediate variety v:

$$z_i(\varphi,v)=\min_{j=0,1}\{p_{ij}(\varphi)\xi_{ij}(\varphi,v)\},\ Pr(\xi_{ij}(\varphi,v)\geq t)=e^{-t^{\theta}},\ \theta>0 \quad (8)$$

The exporting firm solves the procurement problem in Equation (8) and sources each variety v from the region that offers the lowest delivered cost. The probability that the region j=0,1 is the cost-minimizing supplier is:

$$\chi_{ij}(\varphi)=\frac{p_{ij}(\varphi)^{-\theta}}{\sum_{j=0}^{1}p_{ij}(\varphi)^{-\theta}} \quad (9)$$

For a continuum of intermediate varieties and independent Frechet adjustment-cost shocks, the Law of Large Numbers implies that $\chi_{ij}(\varphi)$ equals region j's share in the firm's intermediate inputs. The firm's total intermediate input price index P_M is therefore:

$$P_M(\varphi)=\gamma\left[\sum_{j=0}^{1}p_{ij}(\varphi)^{-\theta}\right]^{-\frac{1}{\theta}} \quad (10)$$

[12] As noted, this means that for any given variety, the firm may source from either domestic or foreign suppliers; the quality of the product is identical across origins, but procurement costs differ from the firm's perspective.

Here, $\gamma=\left[\Gamma\left(\frac{\theta+1-\lambda}{\theta}\right)\right]^{\frac{1}{\lambda-1}}$ is a constant derived from the Gamma function $\Gamma(\cdot)$[13].

Let $p_{i0}(\varphi)=\overline{p_{i0}}\varphi^{-1}$, $\overline{p_{i0}}$ be the baseline domestic intermediate input price in the absence of inter-regional technical complementarity. If there is no complementarity, the firm can only buy domestic intermediates at this constant high price $\overline{p_{i0}}$. Higher complementarity means there are more related upstream and downstream firms in other domestic regions producing usable intermediate inputs, which increases competition and lowers the effective domestic price. Foreign-domestic complementarity is assumed constant, so the foreign intermediate price is fixed. Let the effective domestic price be $p_{i1}(\varphi)=\overline{p_{i1}}$.

Thus, the domestic sourcing probability and the firm's total intermediate price become:

$$\chi_{i0}(\varphi)=\frac{\varphi^{\theta}}{\varphi^{\theta}+\left(\frac{\overline{p_{i1}}}{\overline{p_{i0}}}\right)^{-\theta}} \tag{11}$$

$$P_M=\gamma\left[\overline{p_{i0}}^{-\theta}\varphi^{\theta}+\overline{p_{i1}}^{-\theta}\right]^{-1/\theta} \tag{12}$$

3.3 Equilibrium Conditions

Given the capital price r, wage w, and the intermediate input price P_M determined by the degree of technological complementarity φ, the firm's cost-minimization problem is: $minC=P_M M+wL+rK$, s.t.$Y_i=\emptyset_i(\varphi)K_i^{\alpha_K}L_i^{\alpha_L}M_i^{\alpha_M}$. Solving yields the firm's total cost function: $C=\frac{Y}{\emptyset}\times\left(\frac{r}{a_K}\right)^{\alpha_K}\left(\frac{w}{a_L}\right)^{\alpha_L}\left(\frac{P^M}{a_M}\right)^{\alpha_M}$, which satisfies $rK/\alpha_K=wL/\alpha_L=P^M/\alpha_M=C$. The marginal cost is MC:

$$MC=\partial C/\partial Y=\frac{1}{\emptyset(\varphi)}\left(\frac{r}{a_K}\right)^{\alpha_K}\left(\frac{w}{a_L}\right)^{\alpha_L}\left(\frac{P_M}{a_M}\right)^{\alpha_M} \tag{13}$$

Using Equations (5) and (13), profit maximization gives the firm's markup: $\mu_i=\Omega\left(\frac{\tilde{p}e}{MC}\right)-1$, where e is Euler's number and $\Omega(\cdot)$ is the Lambert-W function satisfying $\frac{\partial\Omega(x)}{\partial x}>0$, $\frac{\partial^2\Omega(x)}{\partial x^2}<0$, $\Omega(0)=0$, $\Omega(e)=1$. Thus, total revenue and the share of imported intermediates in revenue are: $p_i y_i=\mu_i mc_i y_i=\mu_i c_i$, $\frac{P_M M\chi_{i1}}{p_i y_i}=\frac{P_M M(1-\chi_{i0})}{(1+\mu_i)c_i}=\frac{\alpha_m}{1+\mu_i}(1-\chi_{i0})$.

Thereby gradually increasing technological activity and reducing in each region-industry face a region-heterogeneous fixed entry cost F. Entry continues until incumbent profits are driven to zero. Imposing zero profit gives: $F=\mu_i MCy_i=\left(\Omega\left(\frac{\tilde{p}e}{MC}\right)-1\right)\times\gamma\left(\ln\frac{\hat{p}}{\Omega\left(\frac{\tilde{p}e}{MC}\right)MC}\right)\frac{E}{\Omega\left(\frac{\tilde{p}}{MC}e\right)}=\gamma\left(\ln\frac{\hat{p}}{\Omega\left(\frac{\tilde{p}e}{MC}\right)MC}\right)\left(E-\frac{E}{\Omega\left(\frac{\tilde{p}}{MC}e\right)}\right)$. As can be learned from $\frac{\partial F}{\partial\varphi}>0$, regions with a higher degree of technical complementarity face higher entry costs. This aligns with the earlier discussion: although innovative hub cities enjoy higher complementarity, capacity saturation raises factor prices and therefore raises entry costs (Ye et al., 2014). As a result, more firms choose to enter peripheral innovative regions, which gradually increases technological activity and reduces the regional gap in complementarity (Zheng et al., 2023).

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[13] The parameter restriction θ+1-λ>0 ensures that the price index is well-defined.

3.4 Firm Export DVAR

Following Kee & Tang (2016), the domestic value-added ratio of firm exports $DVAR_i$ can be expressed as:

$$DVAR_i=\frac{p_i y_i - P_M M(1-\chi_{i0})}{p_i y_i}=1-\frac{P_M M(1-\chi_{i0})}{(1+\mu_i)c_i}=1-\frac{\alpha_m}{1+\mu_i}(1-\chi_{i0})=1-\frac{\alpha_m}{\Omega\left(\frac{\tilde{p}}{mc(\varphi)}e\right)}\frac{\left(\frac{\overline{p_{i1}}}{p_{i0}}\right)^{-\theta}}{\varphi^{\theta}+\left(\frac{\overline{p_{i1}}}{p_{i0}}\right)^{-\theta}} \quad (14)$$

Taking the natural logarithm of both sides (a positive monotonic transformation that preserves functional properties), and combining with the firm productivity function and Equation (11), gives:

$$\frac{\partial \ln DVAR}{\partial \varphi}=\underbrace{\zeta\frac{A_i e^{\varphi}}{\emptyset(\varphi)^2}}_{\text{Productivity effect>0}}\underbrace{+\frac{\alpha_M}{\emptyset(\varphi)}\zeta\left(\frac{P_M}{a_M}\right)^{-1}\gamma\left[\overline{p_{i0}}^{-\theta}\varphi^{\theta}+\overline{p_{i1}}^{-\theta}\right]^{-(1+\theta)/\theta}\varphi^{\theta-1}+\frac{\theta\varphi^{\theta-1}}{\varphi^{\theta}}}_{\text{Intermediate input effect>0}} \quad (15)$$

where: $\dfrac{\dfrac{\partial\Omega\left(\frac{\tilde{p}}{mc(\varphi)}e\right)}{\partial\frac{\tilde{p}}{mc(\varphi)}e}\dfrac{\tilde{p}}{emc(\varphi)^2}}{\Omega\left(\frac{\tilde{p}}{mc(\varphi)}e\right)}\left(\dfrac{r}{a_K}\right)^{\alpha_K}\left(\dfrac{w}{a_L}\right)^{\alpha_L}\left(\dfrac{P_M}{a_M}\right)^{\alpha_M}=\zeta.$

We pinpoint two critical mechanisms through which inter-regional technical complementarity dramatically influences firms' export DVAR: (1) The Intermediate Input Effect. Products are the tangible embodiment of technology. At the product level, inter-regional complementarity manifests directly: it creates a superior fit between locally produced goods and the fundamental materials and key intermediate inputs flowing from other regions. Even when foreign intermediate quality and price are fixed, rising technical complementarity signals a flourishing ecosystem of domestic firms producing or developing usable inputs. As these domestic technological capabilities mature, local inputs become increasingly attractive—and often superior—in both price and quality to foreign alternatives. The inevitable result is that firms pivot to using more domestic intermediate inputs, directly bolstering the domestic value content embedded in their exports. (2) The Productivity Effect. Productivity is the engine of a firm's economic success and the primary lever for elevating domestic value-added. A firm's TFP is immediately impacted by the degree of technical complementarity in its region. Firms in highly complementary areas gain access to a deep pool of shared, ready-to-use technological knowledge. This strategic advantage enables them to apply knowledge directly in production and R&D, reducing operating costs. Crucially, these technological externalities free firms from the costly, time-consuming necessity of original, from-scratch innovation. Instead, they leverage complementary knowledge to accelerate their technological ascent and innovation efficiency, creating proprietary new techniques and products through strategic recombination and refinement. In essence, inter-regional complementarity fuels firm productivity by accelerating innovation and reducing operational barriers, ultimately translating into higher export DVAR.

Based on this theoretical model, we propose:

Hypothesis 1: Inter-regional technical complementarity helps raise firms' export DVAR.

Hypothesis 2: Inter-regional technical complementarity increases firms' export DVAR primarily by expanding the use of domestic intermediate inputs and by raising firms' TFP.

4. Empirical Analysis

4.1 Model Specification

We estimate the following baseline regression model:

$$dvar_{ijkt}=\beta_0+\beta_1 C_{jkt}+\beta_2 Controls_{ijkt}+\mu_t+\mu_i+\varepsilon_{ijkt} \quad (16)$$

where, C_{jkt} measures the degree of technological complementarity between industry k in city j and the same industry k in all other cities in year t; $dvar_{ijkt}$ denotes the export DVAR of firm i in industry k, city j, year t; μ_t and μ_i are year and firm fixed effects; ε_{ijkt} is the error term, clustered at the firm-level. The vector $Controls_{ijkt}$ includes covariates that may jointly influence both regional technological complementarity and firms' export domestic value-added, including: (1) Share of external capital, measured by (international capital + capital from Hong Kong Special Administrative Region (SAR), Macao SAR and China's Taiwan region) / paid-in capital; (2) Share of state capital: state capital / paid-in capital; (3) Firm size: log of employment; (4) Firm age: current year - year of establishment + 1; (5) Fixed assets: log of total fixed assets; (6) Capital intensity: log of total assets per employee; (7) General-trade share: general-trade export value / total export value; (8) Firm patents: log of 1 + the number of invention patent applications; (9) Regional patents: log of 1 + total invention patent applications in the same region-industry. All continuous variables are winsorized at the 0.5% and 99.5% percentiles. See Table 3 for descriptive statistics.

TABLE 3. Descriptive statistics

Variable	Observations	Mean	SD	Min	Max	p10	p90
Export DVAR	405,493	0.66	0.28	0	1	0.21	0.95
Technological complementarity	405,493	0.17	0.14	0	0.61	0	0.35
Foreign share	405,493	0.34	0.44	0	1	0	1
State share	405,493	0.01	0.10	0	1	0	0
Firm size	405,493	5.47	1.07	2.63	8.70	4.09	6.79
Firm age	405,493	9.34	6.94	0	54	3	17
Fixed assets	405,493	9.20	1.66	4.82	14.29	7.10	11.33
Capital intensity	405,493	5.19	1.09	0.25	11.63	3.83	6.58
General-trade share	405,493	0.73	0.39	0	1	0	1
Firm patents	405,493	0.08	0.34	0	2.56	0	0
Industrial agglomeration	405,493	5.16	14.33	0	129.39	0	9.12
Regional patents	405,493	1.76	2.04	0	9.54	0	4.69

4.2 Baseline Regression Results

Table 4 summarizes the benchmark estimates. Column (1) reports OLS results with only firm and year fixed effects. Column (2) adds the complete set of control variables. The coefficient on technological complementarity is positive and significant at the 1% level. Substantively, a one-unit increase in complementarity raises the export DVAR of firms in that city-industry by 0.02 units. A natural concern is that measured complementarity may reflect greater local industrial agglomeration or more local patenting, rather than genuine cross-regional complementarity. To address this, we follow Shao & Su (2019) and construct a three-digit industry agglomeration index while also controlling for total invention patent applications in the same region-industry. The coefficient remains stable and significant, indicating that the effect is not driven solely by local industry strength. Finally, firms in the same city-industry may share correlated shocks or similar export patterns. Column (4) therefore reports city-industry clustered standard errors. The complementarity coefficient remains robust and significant, confirming that within-region correlation among firms' DVAR does not overturn our findings.

TABLE 4. Baseline regression results

Variable	(1)	(2)	(3)	(4)
	DVAR	DVAR	DVAR	DVAR
Technological complementarity	0.01** (0.00)	0.02*** (0.00)	0.02*** (0.00)	0.02* (0.01)
Industrial agglomeration			-0.00*** (0.00)	-0.00* (0.00)
Regional patents			0.00*** (0.00)	0.00*** (0.00)
Control variables	No	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes
Observations	405493	405493	405493	405493
R^2	0.57	0.57	0.57	0.57

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively (applies to all tables). Standard errors in Columns (1)-(3) are clustered at the firm-level; Column (4) clusters at the prefecture-city level.

4.3 Robustness Checks

4.3.1 Omitted variables

Controlling for Regional Fundamentals. A key concern is that complementarity and firm-level DVAR may both be driven by unobserved regional characteristics. Regions such as the Yangtze River Delta and Guangdong Province exhibit stronger technological capabilities and more extensive mid- to high-end industrial structures. These regions are naturally more likely to (i) exhibit higher technological complementarity with other cities and (ii) host firms positioned higher in GVCs. In such cases, baseline estimates might overstate the actual complementarity effect. Additionally, broader regional fundamentals—economic development, market accessibility, and basic research capacity—may jointly influence both complementarity and DVAR. For example, foundational research significantly boosts local innovation (Akcigit et al., 2021), thereby raising technological complementarity and enhancing local firms' innovative capacity through knowledge diffusion. To address these concerns, Column (1) of Table 5 incorporates these regional variables directly into the regression. The estimated coefficient on technological complementarity becomes slightly smaller but remains statistically significant, indicating that the main effect does not hinge on any particular set of regional controls.

4.3.2 Excluding firms that relocate across cities

Another potential source of bias is firm migration. If firms from other regions relocate into high-complementarity cities to capitalize on technological externalities—especially firms with stronger innovation capabilities—their inherently higher DVAR could artificially inflate our estimates. To test this, we exclude all firms that moved across cities during the sample period. Column (2) shows that the coefficient barely changes relative to the baseline, suggesting that firm relocation does not materially affect our results.

4.3.3 Accounting for off-site R&D activities

Large firms may decouple production and R&D—given China's low labor costs but relatively limited human capital in the early 2000s—locating manufacturing locally while conducting R&D in more advanced jurisdictions (domestic or international). Such organizational structures could weaken the observed relationship between local technological complementarities and firm-level DVAR. In this scenario, the baseline estimate may represent only a lower bound of the actual effect. In the absence of branch-level R&D data, we follow Chakraborty et al. (2024) and exclude the top 10% of firms by annual revenue—those most likely to operate global R&D networks. Column (3) of Table 5 indicates that if the sample of large firms is further excluded, the findings of this paper are further strengthened.

4.3.4 Export upstreamness

While the export DVAR captures how much of a firm's export value is created at home, it does not fully reveal where the firm is positioned along the GVC. A firm may retain high domestic value yet remain concentrated in low-value final assembly. To address this limitation, we compute each firm's export upstreamness—the extent to which its exports are used as intermediate inputs rather than final goods. A higher upstreamness score indicates that the firm is farther from labor-intensive assembly and closer to higher-value segments, such as specialized components or frontier technologies. The regression results show that technological complementarity significantly increases firms' upstreamness in exports. This finding indicates that inter-regional technological complementarity promotes value chain upgrading on multiple fronts: it not only raises domestic value capture but also helps firms move toward more sophisticated, upstream activities in the global production network.

4.3.5 Placebo test

To verify that our estimated causal effect truly reflects inter-regional technological interaction—rather than spillovers from local innovation dynamics—we conduct a placebo test. The procedure is as follows: First, identify minimally linked industries. Using *China's Input-Output Tables* (2002, 2007, 2012), we identify, for each industry, the sector with which it has the weakest intermediate input connection. Second, construct a placebo complementarity measure. We insert the inter-regional technological complementarity of this minimally related industry into Equation

(5) for regression. This placebo variable, by construction, removes local industry innovation trends (since it uses a different sector), carries no meaningful technological complementarity for the focal industry, and therefore cannot capture the interaction mechanism emphasized in our theory. The expectation is straightforward: its coefficient should be zero. Consistent with theory, Table 5 Column (5) shows no significant relationship between the placebo complementarity measure and firm DVAR. This confirms that local spillovers or coincidental co-movements do not drive our main results. The effect is rooted in genuine cross-regional technological complementarity.

TABLE 5. Robustness checks

Variable	(1)	(2)	(3)	(4)	(5)
	With control variables	Excluding cross-city migration	Excluding off-site r&d	Firm upstreamness	Placebo test
Technological complementarity	0.01** (0.00)	0.01** (0.00)	0.02*** (0.00)	0.01** (0.00)	
Minimum associated technical complementarity					-0.00 (0.00)
Located in yrd/prd region dummy	-0.16*** (0.05)				
GDP per capita	0.00*** (0.00)				
Market accessibility	0.01*** (0.00)				
Basic research level	0.00*** (0.00)				
Control variables	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	405,493	377,667	363,058	405,493	405,493
R^2	0.57	0.58	0.58	0.30	0.57

Note: Standard errors are clustered at the firm-level (all tables follow).

4.3.6 Long-term effects

Our analysis has primarily concentrated on the immediate, short-run impact of inter-regional technical complementarity on firm performance, suggesting the observed results may reflect changes within a relatively short time frame. However, technical complementarity can also generate amplified effects over an extended time horizon through technological accumulation. To investigate these long-term dynamics, we re-estimate the model by utilizing lagged complementarity, as shown in Equation (17):

$$dvar_{ijkt+n}=\beta_0+\beta_1 C_{jkt}+\beta_2 Controls_{ijkt}+\mu_i+\mu_t+\varepsilon_{ijkt} \quad (17)$$

In this specification, where n= 1, 2, 3, 4, 5, the equation remains essentially consistent with Equation (5) but incorporates the effects of technical complementarity across time spans of one to five years ahead. The regression results indicate that inter-regional technical complementarity continues to exert a significant positive influence on firms' DVAR over this five-year window. As shown by the estimated coefficients in Figure 6, the effects of technical complementarity lagged by one to five years are in fact markedly stronger than those observed in the baseline regression. This demonstrates that the influence of technical complementarity persists in both the short and the long term.

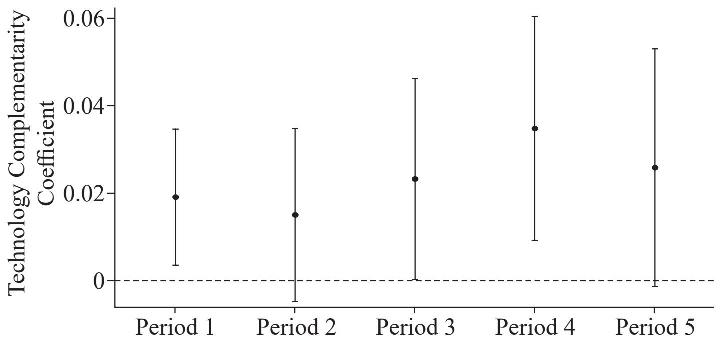

Fig. 6. Long-Term effects of technological complementarity on DVAR

4.4 Instrumental Variable Analysis

Although the preceding sections attempt to mitigate endogeneity by adding potentially omitted controls and adjusting the sample, concerns may still arise from unobservable factors, measurement errors, or reverse causality. To address these issues, this paper adopts an instrumental variable strategy.

The instrument is constructed as the product of the industrial policy difference between the province in which a city is located and other provinces, and the city's market accessibility. The logic is straightforward: the technical complementarity between a region and other cities is jointly shaped by the region's own technological capacity (linked to policy support) and its connectivity with external cities (related to market accessibility). Yu et al. (2016) show that China's industrial policies—particularly those outlined in the Five-Year Plans—significantly spur innovation in the industries they encourage. Accordingly, the stronger the support a local government provides to an industry relative to other regions, the higher that industry's local development level and the broader and deeper its technological deployment, thereby increasing the likelihood of technical complementarity with different areas. In contrast, when a region has a limited technological base in a given industry, its technological proximity to the other regions within the same broad category is smaller, reducing the probability of complementarity. Market accessibility is another essential condition for inter-regional technical complementarity. It facilitates the rapid movement of people and information between cities and eases the transportation of goods. In doing so, it captures the degree of connectivity between a region and cities of different economic scales, closely reflecting the concept of inter-regional linkage embedded in technical complementarity. Following Bao et al. (2023), this study measures provincial industrial policy differences using the stated attitudes toward industries in provincial Five-Year Plans (the Ninth, Tenth, Eleventh, and Twelfth Plans)[14]. Attitudes in these plans are categorized as encouraged (3), neutral (2), or restricted (1). Additional

[14] The industry is defined according to the two-digit level of the National Economic Classification.

support from local or central government is accounted for by adding 1 if the industry is designated as a provincial or national priority. This yields each province's policy support attitude for each industry. The industrial policy difference is then defined as the ratio of a province's support attitude to the average support attitude for that industry across all provinces. The instrumental variable is therefore given by: $IV_{jkt} = \frac{policy_{pkt}}{\frac{\sum_p policy_{pkt}}{31}} \times marketaccess_{jt}$[15], where $policy_{pkt}$ denotes the support attitude of province p (where city j is located) toward industry k in year t, and $marketaccess_{jt}$ represents the market accessibility of city j in year t.

A necessary condition for the validity of the Two-Stage Least Squares (2SLS) estimates is that the instrumental variable satisfies the exclusion restriction, conditional on the included controls. To address concerns about this assumption, this paper conducts four sets of tests to determine whether the instrument may directly influence firm DVAR through other channels. First, we examine whether the instrument affects a firm's market competition intensity[16], its receipt of government subsidies, or its labor productivity. Industrial policy typically promotes the development of local firms by attracting new investment and expanding fiscal and tax incentives (Yu et al., 2016). When a province adopts a more supportive stance toward a particular industry than other provinces, local firms may benefit from increased subsidies and tax rebates, and the resulting inflow of new entrants may heighten market competition. However, the placebo tests show that the instrument—constructed as the product of industrial policy differences and market accessibility—is unrelated to any of these factors. Second, we consider whether the instrument might influence a firm's import input share, since market accessibility could theoretically affect import behavior through shipping time or transport costs. The regression evidence in Table 6 alleviates this concern, indicating that the instrument is not significantly associated with import input shares. Taken together, these placebo tests suggest that the interaction of industrial policy differences and market accessibility constitutes a reasonable and valid instrument.

TABLE 6. Placebo test results

Variable	(1)	(2)	(3)	(4)
	Market competition	Subsidy	Labor productivity	Import share
Instrumental variable	-0.00 (0.00)	-0.00 (0.00)	-0.01 (0.01)	0.00 (0.00)
Year fixed effects	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Observations	405,493	405,493	405,493	405,493
R^2	0.72	0.31	0.80	0.66

Note: All regressions control for the same set of variables as in the baseline specification, as well as firm fixed effects and year fixed effects. Standard errors are clustered at the firm level.

Table 7 presents the instrumental variable estimation results. The first stage regression in

[15] The division by 31 in the denominator accounts for the 31 provincial-level administrative units (provinces, autonomous regions, and municipalities) included in the sample.

[16] Market competition level: measured as the Herfindahl-Hirschman Index (HHI): the sum of squared shares of each firm's operating revenue in the total operating revenue of its local industry.

Column (1) shows that the F-statistic is well above 10, consistent with expectations and indicating a strong positive relationship between the instrument and regional technical complementarity, thereby satisfying the relevance condition. Columns (2) and (3) report the reduced form and 2SLS estimates, respectively. The 2SLS results indicate that a one-unit increase in inter-regional technical complementarity raises firm DVAR by about 0.21 units—roughly ten times larger than the baseline OLS estimate. To address potential concerns that provinces may introduce additional policies to maintain policy continuity, we further include province-year fixed effects and the variables used in the placebo tests. When all of these controls are incorporated simultaneously, the 2SLS coefficient remains 0.21 (Column (4)), closely matching the estimate in Column (3). Economic significance: During 2000-2014, inter-regional technical complementarity increased by an average of 0.18 units. Based on the Column (4) estimate, this implies that firms' export DVAR rose by approximately 3.8 percentage points (≈ 0.18 × 0.21 × 100%), explaining about 25% of the growth in Chinese exporting firms' DVAR over the same period.[17]

TABLE 7. Instrumental variable estimation results

Variable	(1)	(2)	(3)	(4)
	First stage	Reduced form	2SLS	2SLS
Instrumental variable	0.01*** (0.00)	0.07*** (0.00)		
Technical complementarity			0.21*** (0.05)	0.21*** (0.05)
Placebo variable	No	No	No	Yes
Province-year fixed effects	No	No	No	Yes
K-P rk Wald F	747.41			
Observations	405493	405493	405493	405493
R^2	0.57	0.86	0.01	0.02

Note: All regressions control for the same set of control variables, firm fixed effects, and year fixed effects as in the baseline specification. Standard errors are clustered at the firm level.

To further assess the robustness of the instrumental variable strategy, this paper relaxes the conventional assumptions underlying IV estimation and employs two widely used methods for handling imperfect instruments. First, we apply the plausibly exogenous IV approach proposed by Conley et al. (2012). This method allows the instrument to affect the dependent variable through an omitted channel, subject to a bounded parameter range or prior distribution. Based on these priors, we construct confidence intervals for the regression coefficients to evaluate whether the estimates remain robust even when the exclusion restriction is only approximately satisfied. Second, we adopt the Kinky Least Squares (KLS) estimator developed by Kiviet (2020). Unlike conventional 2SLS, which relies entirely on the validity of the instrument, the KLS method does not depend on the instrument at all. Instead, it corrects OLS bias by restricting the admissible correlation between

[17] According to calculations, the average DVAR of Chinese exporting firms increased by 0.1521 from 2000 to 2014.

the endogenous regressor and the error term within a plausible range. The re-estimated results indicate that our findings do not hinge entirely on the strict exclusion restriction. Even when allowing for approximate exogeneity, the estimated effect of technical complementarity on firm DVAR remains significant.

TABLE 8. IV estimation under relaxed assumptions

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	μ=0	μ=0.0001	μ=0.001	Endogenous correlation	Endogenous correlation	Endogenous correlation
	ω=0.00001	ω=0.00001	ω=0.0001	(0)	(-0.01)	(-0.02)
Technical complementarity	0.14***	0.14***	0.13***	0.01**	0.11***	0.21***
	(0.01)	(0.01)	0.04	(0.00)	(0.01)	(0.02)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	No	No	No
Industry/city fixed effects	No	No	No	Yes	Yes	Yes
Observations	405,493	405,493	405,493	405,493	405,493	405,493

Note: μ and ω denote the mean and variance of the specified prior distribution, which is assumed to follow a normal distribution. Because the number of firm-level observations is vast, it is computationally infeasible to control for firm fixed effects when applying the kinkyreg command in the KLS estimator. As a practical alternative, industry and city fixed effects are included as supplementary controls.

5. Mechanism and Heterogeneity Analysis

5.1 Mechanism Analysis

Building on the earlier theoretical discussion, we argue that technical complementarity may enhance a firm's position in the value chain through two channels: (1) increasing the intensity of domestic intermediate input use and (2) improving firm productivity. In this section, we provide empirical evidence for these mechanisms by directly regressing the relevant mechanism variables.

5.1.1 A firm's productive capacity is fundamentally grounded in technology

Under a framework of product specialization, an increase in inter-regional technical complementarity implies that regions are jointly engaging in technological absorption and reinvention. This process strengthens domestic upstream and downstream production capabilities, enabling the provision of a wider array of higher-quality domestic intermediate inputs that better align with firms' needs, while simultaneously lowering the relative price of domestic inputs compared with foreign ones. As a result, domestic exporters increasingly adopt domestic intermediate inputs, gradually substituting for foreign inputs. This shift embeds more domestic value in exported products and ultimately elevates the firm's position within GVCs. Following Gao et al. (2018), we measure domestic intermediate input intensity as the share of domestic intermediate factor expenditure in firm sales. Domestic intermediate factor expenditure equals total intermediate input minus the import value of foreign intermediate products[18]. Column (1) of Table 9 presents the regression results for domestic intermediate input intensity. A one-standard-deviation increase in inter-regional technical complementarity raises the firm's share of domestic intermediate input use by roughly 18%. Moreover, domestic substitution implies that firms source intermediate inputs from the same domestic industry across a broader regional scope, which should manifest as increased domestic sales by these industries in other regions. To test this, we regress technical complementarity on domestic sales[19] (Column 2). The results further support this mechanism. Taken together, the evidence suggests that the rise in domestic intermediate input intensity occurs as exporting firms reconfigure their upstream supply chains by shifting procurement from foreign to domestic suppliers. This not only stimulates the growth of related industries in other domestic regions, fostering inter-regional co-development, but also strengthens firms' resilience to external shocks—an especially valuable attribute amid the current wave of global supply chain disruptions.

5.1.2 TFP effect

Firm TFP directly influences both a firm's export decisions and the DVAR of its export products (Kee & Tang, 2016). On the one hand, technical complementarity refers to the spatial proximity of production and technological spaces across regions. To minimize costs and maximize profits, local firms tend to transfer certain stages of their R&D or production specialization to complementary regions, engaging in technical or capacity collaboration. Compared with local production or R&D, areas that accept this collaborative capacity typically have lower factor costs due to their specialized characteristics. Through this complementary process, firms achieve technological progress and optimal internal resource allocation, thereby enhancing their TFP. On the other hand, regional technical complementarity implies that firms in different regions have already pioneered the discovery of technological or product innovation paradigms closely related to the local industry. As previously discussed, the technological source for most manufacturing firms has shifted from geographical concentration to dispersion, meaning the necessary technology originates not only locally but increasingly from other regions. This allows firms engaged in production and R&D within the same, highly complementary fields to more readily utilize existing complementary technology, leading to faster expansion in process innovation, product innovation, or diversification. This is manifested as higher innovation efficiency and productivity. Innovation efficiency is a critical component of firm productivity. Here, we separately regress firm productivity[20] and innovation efficiency. The measurement of innovation efficiency follows the method of Hirshleifer et al. (2013), which measures it as the number of invention patent

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[18] We use the domestic intermediate trade share as a proxy because direct data on domestic intermediate input prices are difficult to obtain.

[19] Domestic sales revenue is computed as the sum of (sales revenue minus export revenue) for all firms in the same industry nationwide, excluding those in the focal region.

[20] Given the presence of firm exits in the Industrial Enterprise Database, we estimate TFP using the Olley-Pakes (OP) method. This approach effectively addresses sample selection bias arising from the unbalanced panel structure and the endogenous nature of firm exit.

applications generated per unit of R&D expenditure. This metric reflects the conversion efficiency between innovation inputs and outputs. It is particularly suitable for capturing how firms enhance efficiency through R&D that involves modifying, improving, and combining complementary technologies. The results presented in Columns (3) and (4) of Table 9 validate our previous hypothesis. Through this cross-validation across different aspects, we confirm that inter-regional technical complementarity indeed has a significant promotional effect on firm productivity.

TABLE 9. Mechanism analysis results

Variable	(1)	(2)	(3)	(4)
	Share of domestic intermediate input	Domestic sales volume in other regions	Firm productivity	Innovation efficiency
Technical complementarity	0.01*** (0.00)	0.13*** (0.01)	0.54** (0.00)	0.01** (0.00)
Control variables	Yes	No	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	No	Yes	Yes
City/industry fixed effects	No	Yes	No	No
Observations	405393	33414	405493	97983
R^2	0.66	0.96	0.69	0.76

5.2 Heterogeneity Analysis

To develop a more precise and more nuanced understanding of how inter-regional technical complementarity contributes to firms' value chain upgrading, we conduct a series of heterogeneity analyses.

5.2.1 Heterogeneity by human capital level

A firm's human capital (HC) plays a crucial role in its ability to absorb the external benefits generated by inter-regional technical complementarity. Empirically, HC can influence this effect in multiple ways. Technology Discovery Perspective: Firms with higher HC possess stronger R&D capabilities and are more adept at proactively identifying technological sources or suppliers whose capabilities complement their own (Tombe & Zhu, 2019). These firms are more likely to discover and leverage external technologies. By contrast, firms with lower HC face a reduced chance of successful technology discovery even when exposed to the same external knowledge base. Knowledge Diffusion Perspective: High-HC firms may already be close to the technological "frontier," meaning that while technical complementarity can still expand their innovation space, the marginal impact may be limited. Lagging firms, however, are more likely to absorb and imitate technologies diffused from leading firms, thus exhibiting a more substantial complementarity effect. The group regression results in Table 10 (Columns 1 and 2) show that technical complementarity has a significant impact on both high- and low-HC groups. This indicates that both technology discovery and knowledge diffusion mechanisms are at work, but the diffusion mechanism is stronger—helping narrow performance gaps across firms.

5.2.2 Heterogeneity by regional innovation status

Next, we examine how the effect varies across regions with different innovation roles. Leading regions, endowed with superior geography and innovation resources, often emerge as innovation centers. However, as technological development becomes more complex and costly, no single city can internalize all innovative activities. Innovation centers, therefore, increasingly shift manufacturing and even some R&D functions outward, forming complementary technological relationships with surrounding regions. These innovation periphery regions, in turn, participate more deeply in center-led technological and industrial specialization, accelerating their technological upgrading and competitiveness. Thus, we expect technical complementarity to exert a stronger effect on firms in innovation periphery regions. Following Zheng et al. (2023), we identify China's 20 innovation center cities[21] and classify firms according to whether they are located inside or outside these centers. Table 10 (Columns 3 and 4) shows that inter-regional technical complementarity significantly enhances value chain upgrading for both groups, but the effect is noticeably stronger in innovation periphery regions.

5.2.3 Heterogeneity by market integration level

Market fragmentation can severely constrain the benefits of technical complementarity by impeding inter-regional diffusion of technology, cooperation, investment, and trade. Transportation infrastructure—an essential driver of domestic market integration (Faber, 2014)—plays a decisive role. Well-developed transport networks increase mobility and logistics efficiency, effectively reducing the geographical and administrative barriers that contribute to market segmentation. Using the market accessibility index constructed following Wu et al. (2021), we measure regional differences in market integration. The grouped regressions in Table 10 (Columns 5 and 6) show that the positive effect of technical complementarity on value chain upgrading is stronger in regions with higher market integration.

Taken together, these heterogeneity results echo the empirical patterns observed earlier. Inter-regional technical complementarity indeed plays a vital role in narrowing performance gaps across firms, primarily by reducing differences between innovation centers and periphery regions, as well as between high- and low-HC firms. This contrasts with the findings of Akcigit & Ates (2023), who document a decline in technological diffusion in the United States and a widening productivity gap between frontier and laggard firms. A plausible explanation for the difference is that China's continuous efforts to promote regional integration and build an innovation-oriented national system have helped reduce market fragmentation, thereby strengthening the operation of technical complementarity. The heterogeneity analyses thus corroborate our main argument and enrich the discussion on how technological diffusion shapes firm- and region-level disparities in the Chinese context.

[21] Innovation center cities are defined as the top 20 cities ranked by technological sophistication.

TABLE 10. Heterogeneity analysis results

2SLS Estimates	(1) Low human capital	(2) High human capital	(3) Innovation center	(4) Innovation periphery	(5) Low accessibility	(6) High accessibility
Technical complementarity	0.28*** (0.08)	0.19** (0.07)	0.27** (0.10)	0.13*** (0.05)	0.16*** (0.05)	0.32** (0.12)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	208380	186131	216590	186516	213943	173173
R^2	0.00	0.02	0.00	0.02	0.02	0.00

Note: In the group regressions, the ivreghdfe command automatically drops observations with only one year of data, resulting in slight differences in sample size across subgroups.

5.3 Market Manifestations of Value Chain Upgrading

The preceding results show that inter-regional technical complementarity has substantial economic significance and markedly enhances firms' positions within the GVC. While this effect can be explained through productivity improvements and increased reliance on domestic intermediate inputs, the question remains: How does the benefit of technical complementarity actually manifest in firms' market performance during GVC upgrading? Prior literature argues that a country's product-space complexity reflects the sophistication of its production, innovation, and technological capabilities (Hidalgo et al., 2007)—a logic that applies equally to firms. Firms trapped in the GVC "capture" stage tend to exhibit low product diversity: they specialize in a limited set of low-tech goods and export primarily to a small set of destinations (Lü & Deng, 2020). In contrast, firms that successfully upgrade their GVC position should display: higher product quality and complexity, broader product scope, and more diversified export destinations. Moreover, as firms move up the value chain and strengthen their market power, their export markups should also rise.

Following Shao & Su (2019), we measure firm-level export quality using export price, quantity, and destination information. Product scope and export reach are quantified by the number of HS6-digit product categories exported and the number of export destinations in each year. Export markups are estimated using the production function approach of De Loecker & Warzynski (2012). The regression results in Table 11 strongly validate the expectations that the coefficients on technical complementarity are significant at the 1% level across all specifications. This indicates that technical complementarity provides firms with richer external innovation resources—raising product quality—and supports product discovery, allowing firms to broaden both their product portfolios and destination markets. Simultaneously, it enhances firms' cost markups, reflecting stronger market power. Taken together, these outcomes constitute the micro-level market manifestations of firms' successful GVC upgrading enabled by inter-regional technical complementarity.

TABLE 11. Market manifestations of value chain upgrading

Variable	(1) Firm Product Quality	(2) Export Product Volume	(3) Number of Export Destinations	(4) Firm Cost Markup
Technical complementarity	0.01***	2.85***	0.71***	0.01***
	(0.00)	(0.28)	(0.23)	(0.00)
Control variables	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Observations	405493	405493	405493	405493
R^2	0.83	0.79	0.87	0.56

6. Research Conclusions and Policy Implications

This study investigates how inter-regional technical complementarity shapes firms' ascent in GVCs, measured through the DVAR in export. The main findings are as follows: (1) Causal impact and economic magnitude. Inter-regional technical complementarity significantly enhances firms'GVC positions within a region. This conclusion remains robust after addressing concerns related to omitted variables, firm relocation, and off-site R&D. Using an instrumental variable constructed from the interaction of inter-provincial industrial policy differences and regional market accessibility, we find that a one-unit increase in technical complementarity raises firm-level DVAR by approximately 0.2 units. Further calculations show that the improvement in China's inter-regional technical complementarity from 2000 to 2014 accounts for about 25% of the growth in export DVAR among Chinese firms—highlighting its substantial economic significance. (2) Mechanisms and Market-Level Manifestations. Technical complementarity facilitates GVC upgrading primarily by improving firms' TFP and increasing the share of domestic intermediate inputs. In the market, this upgrading is reflected in expanded export product scope, enhanced product quality, a greater number of export destinations, and higher cost markups. (3) Heterogeneity and Equity Effects. The promotional effect is more substantial for firms with lower human capital and those located in innovation periphery regions, thereby narrowing gaps between core and peripheral areas and between human capital front-runners and laggards. The effect is also more significant in areas with higher degrees of market integration, underscoring that effective technology diffusion is essential for complementarity to operate. Therefore, these findings collectively explain why technical complementarity drives firms' GVC upgrading and how it helps reduce firm-level disparities and promote balanced regional development.

Based on the empirical results, we propose the following policy recommendations: (1) Leverage China's unique advantage in inter-regional technical complementarity to support GVC upgrading. The study shows that China's rising regional innovation capacity led to a growing dispersion of technological and production activities across space. Compared with developed economies where innovation resources are more geographically constrained, China is forming a dynamic, complementary system of technological specialization. Thus, policymakers should build and strengthen platforms for inter-regional technical exchange and cooperation, fostering collaboration among research institutes, universities, and enterprises. Increasing fiscal support for cross-regional R&D projects and encouraging enterprise-led innovation alliances will help expand the external benefits of technical complementarity.

(2) Balance innovation incentives with strategic national guidance. If regions "rush" into identical industries, excessive and inefficient competition for resources could arise, potentially leading to nationwide misallocation of factors and the emergence of zombie firms during industry downturns. To prevent this, the government should optimize the innovation policy environment, lower firms' innovation costs, and encourage broader participation among innovation actors. Simultaneously, regions should attract domestic and overseas innovation resources and pursue targeted technological activities aligned with their industrial bases and comparative advantages. This will foster the development of new, quality, productive forces, strengthen local innovation capabilities, and enhance inter-regional technical complementarity.

(3) Accelerate the construction of a unified national market to utilize the benefits of technical complementarity fully. Technical complementarity promotes GVC upgrading primarily through cross-regional factor flows that raise TFP and increase domestic sourcing of intermediate inputs. However, market fragmentation weakens firms' ability to absorb these benefits and disrupts cross-regional procurement of intermediates. Against the backdrop of frequent disruptions in global supply chains, China must support domestic specialization in intermediate goods, improve the flow of domestic economic circulation, and maximize the benefits of technological diffusion and intermediate input linkages. This will promote more balanced regional development.

This paper focuses on the domestic dimension of inter-regional technical complementarity and its impact on Chinese firms' export performance. Emphasizing domestic complementarity does not imply neglecting international technological linkages. As China continues to deepen its openness across broader domains, international technical complementarity remains equally important. Future research could explore how global technological linkages influence Chinese exporters' R&D location decisions, sourcing strategies, and supply chain restructuring. CE

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