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E-commerce and foreign direct investment: pioneering a new era of trade strategies

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This study explores the dynamic interplay between foreign direct investment, e-commerce, and China's export growth from 2005 to 2022 against the backdrop of the rapidly evolving global economy. Utilizing advanced analytical models that combine province- and year-fixed effects with fully modified ordinary least squares and dynamic ordinary least-squares methodologies, we delve into how foreign direct investment and e-commerce collectively boost China's export capabilities. Our findings highlight a significant alignment between China's export expansion and the global sustainable development agenda. We observe that China's export growth transcends mere international investment and digital market engagement, incorporating sustainable practices such as effective utilization of local labor resources and an emphasis on technological advancements. This study also uncovers how knowledge capital and educational attainment positively impact export figures. A notable regional disparity is observed, with the eastern regions of China being more responsive to foreign direct investment and e-commerce influences on export trade compared to their western counterparts. This disparity underscores the need for region-specific policy approaches and sustainable strategies to evenly distribute the benefits of foreign direct investment and e-commerce. The study concludes that while foreign direct investment and e-commerce are crucial for China's export growth, the underlying theme is sustainable development, with technological innovation and human capital being key to ongoing export success. The findings advocate for policies that balance economic drivers with sustainable development goals, ensuring both economic prosperity and environmental sustainability.

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Introduction

In its ascent towards global economic preeminence, China has undergone transformative alterations in its provincial export trade architecture, metamorphosed by the intricate orchestration of economic vectors and technological advents within the globally interconnected milieu. Central to this paradigm shift is the synthesis of foreign direct investment, the burgeoning trajectory of e-commerce, the proper deployment of indigenous labor resources, and tactically channeled technological capital. An adept comprehension of these intricate dynamics becomes essential for informed forecasts pertaining to China's export evolution and its symbiotic relationship with sustainable developmental objectives. The exponential proliferation of China's export vertical can be attributed to its accurate incorporation of foreign direct investment, pivotal in catalyzing technological assimilations, fortifying workforce competencies, and forging novel market corridors. In tandem, the surge in e-commerce has revolutionized market penetration modalities, enabling Chinese offerings to seamlessly infiltrate global commerce arenas. Moreover, China's abundant labor capital, juxtaposed with deliberate technological ventures, has accentuated its competitive foothold in global trade arenas. Yet, the velocity of this expansive trajectory beckons a meticulous assessment through a prism of sustainability, addressing facets of resource optimization, laboral integrity, and ecological prudence.

In the current academic landscape, a significant emphasis has been placed on dissecting the myriad ramifications of foreign direct investment on export enhancement, with studies underscoring its cardinal role in technological integration and amplifying operational efficacy. The integration of e-commerce facets, as delineated by Hao et al. (2023), offered a refined perspective, spotlighting the instrumental role of digital conduits in transcending conventional trade barriers. The interrelation of labor capital, as articulated by Zhang et al. (2016), in concert with technological advancements, as expounded by Autor et al. (2015), underscored the salience of indigenous assets and frontier innovations in the export dialog. However, despite the expansive literature, a comprehensive appraisal amalgamating these aspects, especially within the framework of China's regional disparities, is palpably lacking. From a methodological standpoint, diverse econometric paradigms have been employed in antecedent research, yet province- and year-fixed effect models are increasingly lauded for their analytical precision. The eastern corridors, advantaged by their littoral proximity, have conventionally steered the export zeitgeist. Academic contributions, such as those by Duan et al. (2020), underscored this region's proficiency in harnessing foreign direct investment and e-commerce potentialities. In juxtaposition, the central and western sectors, albeit resource-rich and labor-abundant, evince a marked lag in technological embrace and foreign direct investment influx. This regional polarization, as theorized by Zhong et al. (2022), accentuates the necessity for tailored policy interventions to promulgate balanced and sustainable growth vectors. In this context, our scholarly pursuit seeks to redress the prevailing knowledge chasm. The intricate interplay of foreign direct investment, e-commerce, labor dynamics, and technological innovation in molding China's export tapestry is indubitable. Yet, exhaustive scrutiny, particularly one sensitive to regional grades, stands as an academic imperative. Grounded in methodological robustness and echoing sustainability principles, this study aims to demystify this intricate interconnection, catalyze informed policy deliberations, and buttress China's odyssey towards a sustainable export paradigm.

Drawing upon the aforementioned analytical discourse, this research delves into the complex relationship between foreign direct investment, e-commerce, and the growth of exports in China from 2005 to 2022, situated within the context of a rapidly changing global economic landscape. Using advanced statistical methods, such as province- and year-fixed effects analysis along with fully modified ordinary least squares and dynamic ordinary least-squares methods, the study gives a more complete picture of how foreign direct investment and e-commerce work together to make China's exports stronger. A key aspect of this study is its alignment with the global sustainable development agenda, examining how China's export growth extends beyond basic international investment and digital commerce. It integrates sustainable practices, such as the effective use of local labor and a focus on technological advancement, offering insights into the role of knowledge capital and educational attainment in boosting export figures. Our analysis reveals a pronounced regional variation in the impact of foreign direct investment and e-commerce on export trade, with Eastern China showing greater responsiveness compared to the Western regions. This finding highlights the necessity for region-specific policies and sustainable strategies to ensure a balanced distribution of foreign direct investment and e-commerce benefits across the country. The study's methodology stands out in the existing literature for its comprehensive approach, combining advanced econometric techniques to dissect the multifaceted influences on China's export sector. It addresses a gap in previous research by providing a clearer picture of the interplay between foreign direct investment, e-commerce, and export growth within the unique context of China's evolving economy. The research emphasizes the need for a nuanced understanding of China's position in the global economy, exploring the relationship between foreign direct investment and e-commerce in a way that prior empirical studies have not fully captured. By doing so, the study offers valuable insights for policymakers and stakeholders, advocating for strategies that not only foster economic growth but also align with sustainable development objectives, ensuring the long-term prosperity and environmental sustainability of China's economy.

This study presents several significant contributions to the current academic understanding of China's export sector, particularly focusing on sustainable development. First, our analysis synthesizes the roles of foreign direct investment and e-commerce, offering fresh insights into their collective influence on China's exports. This aspect builds upon the work of Fidrmuc and Korhonen (2010), who underscored the impacts of global capital and digital advancements on emerging economies. Our study extends this perspective by explicitly linking these factors to export growth in the Chinese context. Second, we introduce a nuanced approach by examining regional variations in export performance, moving beyond the limitations of previous studies that often treated China's economy as a uniform entity. Grübler et al. (2007), who emphasized the value of regional analysis in producing more thorough economic insights than national overviews, served as an inspiration for this strategy. Third, our research highlights the role of local labor resources as a key component of sustainable export strategies. This aligns with Sun's (2022) assertion of human capital as a critical driver of economic growth, positioning it as a sustainable asset in China's export framework. Fourth, the study delves into the impact of technological investment on sustainable export growth, expanding upon Qian et al. (2021) thesis that technology is fundamental to achieving green growth. We explore how technological advancements contribute specifically to the sustainability of China's export sector. Lastly, the research advocates for a balanced approach to economic growth and environmental sustainability, echoing Wright's (2019) argument for the necessity of balancing economic development with ecological preservation. Our study furthers this dialog by illustrating how such a balance

can be achieved within the context of China's export dynamics. Together, these facets of our research offer new perspectives on the complex relationship between economic activities, technological innovation, and sustainable development in the context of China's growing role in the global market. These insights are particularly relevant for policymakers and business leaders looking to navigate the challenges and opportunities presented by China's evolving export landscape.

The subsequent sections of this article are structured as follows: section "Literature review" delves into a comprehensive review of extant literature, shedding light on prior research in this domain. In the section "Variables and model", we elucidate the methodological approach, detailing the variables employed and the underlying model. Section "Empirical results" offers a synthesis of the empirical results, coupled with a discussion of the implications. Lastly, the section "Conclusions" culminates with conclusions, policy recommendations, and avenues for future research in this field.

Literature review

In today's global trade environment, the interplay between foreign direct investment and e-commerce has become a critical factor influencing export trends. Current research highlights foreign direct investment's pivotal role in driving technology transfer and expanding markets. Concurrently, e-commerce platforms have revolutionized trading patterns, facilitating instantaneous market connections and broadening international reach. Additionally, elements like labor resource allocation and technological progress intertwine with these primary factors, creating a multifaceted framework that reveals the complexities of modern export strategies.

In contemporary academic discourse, the impact of foreign direct investment on China's export trade has received significant attention. Yet, the complex relationship with e-commerce remains insufficiently explored. The prevailing literature, as seen in the works of Li et al. (2019), Wang et al. (2020), and Jin and Huang (2023), mainly focuses on the direct effects of foreign direct investment on export efficiency through capital infusion and technological transfers. These studies, however, tend to overlook the burgeoning dimension of digital commerce. Addressing this gap, Fu et al. (2016), Chen et al. (2023), and Lei and Xie (2023) provide a more nuanced perspective by acknowledging the role of digital transformation in global trade. They underscore e-commerce's potential to complement foreign direct investment, particularly in enhancing market access for Chinese exports. Expanding on this viewpoint, Qi et al. (2020), Klimenko and Qu (2023), and Yan et al. (2023) examine how e-commerce platforms democratize export opportunities, even for smaller entities, thus amplifying foreign direct investment's impact. The insights of Zhang and Yang (2022), Mahalik et al. (2023), and Cordes and Marinova (2023) served as inspiration for this research's more integrative approach. It goes beyond the traditional analysis of foreign direct investment's influence on exports to include the transformative role of e-commerce. This methodological advancement builds upon and extends the analyses of Götz (2020), Auboin et al. (2021), and Ha (2022), who, despite their thoroughness, did not fully address the synergistic relationship between foreign direct investment and digital trade channels. Aligned with the analytical frameworks of Agarwal and Wu (2015), He et al. (2021), and Shanmugalingam et al. (2023), this study emphasizes a thorough understanding of trade dynamics in the digital era. By incorporating e-commerce as a key variable alongside foreign direct investment, it fills a critical gap in the literature. This approach resonates with the findings of Zhang and Zeng (2023), Xiao and Abula (2023), and Sun et al.

(2024) on the growing influence of digital platforms on trade and extends their work by empirically quantifying this impact within the context of China's export landscape. In conclusion, this research contributes significantly to the existing body of literature by integrating the crucial role of e-commerce. It provides a more comprehensive view of the dynamics shaping China's export trade, thereby addressing a vital need in the ongoing academic conversation.

The existing literature recognizes the impact of e-commerce on China's export trade but lacks a thorough exploration of its synergistic effects with foreign direct investment and traditional trade mechanisms. Previous studies, such as those by Giuffrida et al. (2017) and Li et al. (2019), have primarily focused on the direct impact of e-commerce on market expansion and customer engagement, emphasizing its role in broadening the global reach of Chinese products. However, these studies often treat e-commerce as an isolated factor, not integrating it with broader economic elements like foreign direct investment. A more nuanced perspective is emerging from research such as Blanchard, Jean-Marc (2019), Villegas-Mateos (2022), and Singh and Singh (2022), which begin to address the interaction between e-commerce and foreign direct investment but do not provide a comprehensive analysis. These studies show how e-commerce platforms can enhance export efficiency in conjunction with foreign direct investment, yet they stop short of examining how e-commerce is transforming traditional export models. This research addresses this gap by adopting an integrative methodology, drawing on the approaches of Wang et al. (2021) and Yin and Choi (2023). This methodology extends beyond evaluating the direct effects of e-commerce on exports to also consider its interplay with foreign direct investment. Such an approach expands upon the frameworks used in studies by Zhang (2019) and Phang et al. (2019), which, while insightful, did not fully capture e-commerce's complex dynamics within China's integrated market economy. Additionally, this study aligns with the emerging literature, such as the works of Gao (2018) and Li et al. (2020), advocating for a holistic view of digital trade's role in economic growth. By incorporating a comprehensive array of variables, including technological advancement and digital infrastructure quality, this research provides a more robust analysis than previous studies like those by Katz and Callorda (2018), Sinha et al. (2020), and Wei and Ullah (2022). In conclusion, this study overcomes previous shortcomings in academic research by offering a detailed empirical examination of how e-commerce, in conjunction with foreign direct investment and traditional trade mechanisms, shapes China's export landscape. It contributes significantly to academic discourse by presenting a more complete understanding of e-commerce's role in the modern economy, thus fulfilling a critical need in the ongoing narrative on global trade and digital economics.

In analyzing China's export sector, the influence of labor resource allocation, technological advancements, knowledge capital, and educational attainment, particularly in relation to e-commerce, warrants a deeper exploration. Initial research efforts, exemplified by Bhaumik et al. (2016), Song and Wang (2018), and Liu and Xie (2020), have individually evaluated the impacts of labor and technology on export performance, underscoring their roles in bolstering China's position in international markets. Yet, these studies typically overlooked the integration of e-commerce into their analytical models. Recent scholarly works, including those by Kwak et al. (2019), Elia et al. (2021), and Tang and Li (2023), have started to recognize the combined effect of technological prowess and labor skills within the framework of e-commerce. However, these investigations fall short of comprehensively examining how knowledge capital and education intersect with e-commerce to affect export trends. The

methodologies of Lin et al. (2020), Hanelt et al. (2021), and Abdul-Rahim et al. (2022) served as the foundation for this study's holistic approach to closing this research gap. Our approach is comprehensive, assessing not just the direct impacts of labor, technology, education, and knowledge on exports but also situating these impacts in the context of the growing e-commerce domain. This method expands upon the analytical scope of previous studies like Wei et al. (2020) and Li et al. (2023), which, despite their thoroughness, did not fully delve into the complex relationship between e-commerce and China's export dynamics. Furthermore, our study aligns with the evolving scholarly narrative, as seen in the works of Banalieva and Dhanaraj (2019) and Huang et al. (2023), advocating for an integrated view of digital commerce's interaction with traditional economic variables. By including an extensive analysis of factors such as digital infrastructure and market development in e-commerce, this research offers a more detailed examination than earlier studies by Gorla et al. (2017) and Wang et al. (2024). In summary, this research fills existing gaps in the literature by thoroughly investigating how labor resources, technological investments, knowledge capital, and education, in conjunction with e-commerce, shape the export sector in China. It provides a comprehensive perspective on the synergy between traditional economic elements and digital trade, addressing a critical need in the ongoing discussion of global trade and economic progression.

Variables and model

Variables. Numerous studies have explored the significant impact of foreign direct investment on a nation's export trends, highlighting foreign direct investment's critical role in reshaping export strategies. Researchers like Choong (2012) and Otchere et al. (2016) have pointed out that foreign direct investment not only provides essential capital but also facilitates technological transfer, thereby boosting efficiency and productivity in host countries. Moreover, the aspect of sustainability is increasingly becoming interlinked with foreign direct investment, often bringing eco-friendly technologies and sustainable methodologies to the forefront, enhancing a nation's prospects for long-term export stability, as noted by Perrini and Tencati (2006). Simultaneously, the influence of the digital revolution, particularly the rise of e-commerce, has significantly transformed the nature of exports. Studies by Wang (2010) and Teng et al. (2022) highlight that in China's expanding digital landscape, e-commerce platforms have leveled the playing field, allowing even smaller businesses to access the global market. According to Rita and Ramos (2022), Amornkitvikai et al. (2022), and He et al. (2021), e-commerce is also in line with the global trend towards sustainable trading due to its traceable and transparent nature. Considering these complex interactions, export trade volume becomes an appropriate variable to study, representing the combined and sustainable effects of foreign direct investment and e-commerce. This research, therefore, focuses on the export trade volumes of China's provinces, incorporating foreign direct investment inflows and e-commerce transaction data as independent variables. This approach aims to shed light on their hypothesized influence on provincial export patterns.

To fully grasp the complex factors affecting export trade, it's crucial to look beyond conventional indicators like foreign direct investment and e-commerce. A deeper exploration into academic literature and fundamental economic theories uncovers the critical role of labor resource allocation and technological advancements in shaping export patterns. The foundational Heckscher-Ohlin theorem, supported by research from Castilho et al. (2012) and Antràs et al. (2017), underscores the vital impact of labor resources on global trade trends. Darku (2021) extends

this perspective, emphasizing the sustainability aspects and suggesting that effectively managed labor resources can contribute to more equitable and environmentally responsible trading practices. Additionally, examining the role of technology provides insights into the nuances of export competitiveness. Rooted in Romer's theory of endogenous growth and backed by findings from Jones (2019) and Anzoategui et al. (2019), there is a consensus that deliberate technology investments boost productivity and support sustainable growth through cleaner, more efficient production methods. Zhou et al. (2021) further clarify this idea, showing how sustainable technologies and competitive exports are interlinked. Recognizing the importance of these two factors, this study incorporates labor resource allocation and technological inputs as key control variables. To empirically anchor these theoretical concepts, we use urban employment data from various provinces as indicators of labor resource allocation and local government spending on technology as a reflection of technological investments. Building on the work of Mansion and Bausch (2020), Lyu et al. (2022), and Mohammad Shafiee et al. (2023), this paper also introduces knowledge capital quantified by the number of patent licenses. Following Atkin (2016), Ahmed et al. (2020), and Blanchard and Olney (2017), the paper incorporates education level, measured by the average number of schooling years.

Due to data availability, this paper selects balanced provincial-level data from 2005 to 2022. Since 2005, e-commerce across various Chinese provinces has seen rapid development, making this period particularly relevant to the study's context. The unavailability of data from Tibet necessitates the inclusion of 30 other provinces and municipalities in China, namely Beijing, Tianjin, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The data used in this study is sourced from three official databases, each providing specific insights into our variables of interest. The Bureau of Statistics of China supplies data on export trade volume, knowledge capital, education level, labor resource endowment, and technological investment. Information on e-commerce is obtained from the China E-commerce Report, while data on foreign direct investment is sourced from the Statistical Bulletin of China's Outward Foreign Direct Investment.

Model. In examining the interplay between foreign direct investment and e-commerce on export trade using China's province data, it is imperative to adopt a robust econometric technique that effectively captures both time-invariant and entity-specific heterogeneities. The two-way fixed effects regression model, as elaborated upon by Wooldridge (2010) and advocated by Baltagi (2021), is particularly adept at mitigating potential omitted variable biases in panel data, making it especially suitable for our study's empirical context. By incorporating both entity and time-fixed effects, this approach controls for unobserved province-specific factors that may influence export trade (such as local policies or geographical advantages) and time-specific shocks (like global economic trends or national regulatory shifts) that uniformly affect all provinces. By accounting for these dual dimensions of variability, the model ensures that the estimated effects of foreign direct investment and e-commerce are purged of confounding influences, thus bolstering the credibility of causal inferences drawn from the results. Given the dynamism of China's economic landscape, combined with the evolving trajectories of foreign direct investment and e-commerce, leveraging the two-way fixed effects regression offers a rigorous and

robust approach to discerning their impact on export trade. The model is shown as follows:

$$
\begin{aligned}
\mathrm{logex}_{i,t} = a_0 &+ a_1^+ \mathrm{logfdi}_{i,t} + a_2^+ \mathrm{logec}_{i,t} \\
&+ a_3^+ \mathrm{loglab}_{i,t} + a_4^+ \mathrm{logtec}_{i,t} + a_5^+ \mathrm{logkn}_{i,t} \\
&+ a_6^+ \mathrm{loged}_{i,t} + \eta_i + \delta_t + \epsilon_{i,t}.
\end{aligned} \tag{1}
$$

In Eq. (1), the subscript 'i' represents individual provinces, while t delineates the temporal dimension, capturing the yearly variations. Within this model, ex symbolizes the export trade volume, serving as our dependent variable. On the explanatory side, ec corresponds to e-commerce metrics, 'fdi' quantifies foreign direct investment inflows, 'lab' encapsulates labor resource endowment, and 'tec' signifies the magnitude of technological investment. 'kn' indicates knowledge capital. 'ed' stands for education level. The term a_0 denotes the intercept, providing a baseline measure for our regression. The vector $[a_1, a_6]$ comprises the coefficients estimated for each explanatory variable, reflecting their respective strengths and directions of influence on export trade. To control for potential unobserved heterogeneities, η embodies province-specific fixed effects, while δ accounts for year-specific fixed effects, ensuring that time-invariant provincial attributes and common temporal shocks are appropriately adjusted for. The error term, ϵ, is presumed to follow a white noise process, indicating randomness and the absence of serial correlation. The empirical focal points of this study are the coefficients a_1 and a_2. In our analytical framework, the '+' symbol is strategically used to represent the expected positive effect of various independent variables—including e-commerce, foreign direct investment, labor resource endowment, technological investment, knowledge capital, and education level—on the export volumes of Chinese provinces. This symbolism is central to our hypothesis, positing that these variables play a beneficial role in shaping export trends across different provinces. The underlying premise of this hypothesis is that variables like foreign direct investment, enhanced e-commerce capabilities, and other pertinent factors positively stimulate export activities. In essence, the '+' sign indicates a probable correlation where increases or improvements in these independent variables are likely to correspond with a rise in export volumes from the provinces. Such a correlation is instrumental in dissecting how various economic elements and technological progressions, specific to China's varied regional landscapes, can bolster the nation's export capacity. This exploration is particularly salient for understanding China's export mechanics. It provides a nuanced view of how strategic investments in technology, human capital development, and leveraging local resources can collectively uplift the export sector, reinforcing China's position in the global economy. The '+' sign, therefore, not only signifies a positive correlation but also serves as a gateway to understanding the multifaceted drivers that enhance export efficiency in the context of China's evolving economic landscape.

Robustness test. Considering the relatively modest scale of our sample in this study, there exists a plausible risk of heteroskedasticity and autocorrelation in the outcomes estimated through the use of annual and provincial fixed effects models. These statistical issues could potentially introduce biases into our analytical results, thereby affecting the reliability of our conclusions. To mitigate this challenge, our research strategically implements two advanced econometric methodologies: fully modified ordinary least squares and dynamic ordinary least squares. The fully modified ordinary least-squares technique, a refined version of the ordinary least-squares methodology, is

particularly adept at addressing complexities arising from heteroskedasticity and autocorrelation. The efficacy of this approach in handling such statistical nuances is well documented in the works of scholars such as Pedroni (2001), Christou and Pittis (2002), Trapani (2015), Li et al. (2020), Kripfganz and Sarafidis (2021), Norkutė et al. (2021), and Kheifets and Phillips (2023). These studies validate the use of fully modified ordinary least squares as a robust tool for enhancing the accuracy of econometric estimations, especially in scenarios similar to those in our study. Similarly, the dynamic ordinary least squares method offers a comprehensive solution for addressing the challenges of endogeneity and serial correlation, which are common in time-series data. Research by Chudik and Pesaran (2015), Moon and Weidner (2017), Liu et al. (2020), Ahn and Thomas (2023), Hartono et al. (2023), and Fingleton (2023) underscore the effectiveness of dynamic ordinary least squares in ensuring more precise and reliable results in econometric analysis. This technique, by adjusting for both the lead and lag dynamics of the variables, enhances the accuracy of regression coefficients, thereby providing a more nuanced understanding of the underlying data patterns. Both fully modified ordinary least squares and dynamic ordinary least squares are sophisticated enhancements of the traditional least-squares approach. These methods have been specifically adapted to address the intricate statistical issues inherent in panel data analysis, like the one employed in our study. By incorporating these advanced techniques, we aim to mitigate potential biases arising from heteroskedasticity, autocorrelation, and endogeneity, thereby enhancing the credibility and robustness of our findings. Equation (2) in our study meticulously outlines the application of these methods, demonstrating their integration into our analytical framework to yield more reliable and insightful results.

$$
y_t = \widetilde{\Gamma_{2'1}} D_{1t} + \widetilde{\Gamma_{2'1}} D_{1t} + \tilde{\epsilon}_t. \tag{2}
$$

This outcome is directly derived from the differential regression, as shown in Eq. (3).

$$
\Delta y_t = \widetilde{\Gamma_{2'1}} \Delta D_{1t} + \widetilde{\Gamma_{2'1}} \Delta D_{1t} + \tilde{\epsilon}_t. \tag{3}
$$

Let's consider $\tilde{\Theta}$ and $\tilde{\Psi}$ to represent the long-term covariance matrix calculated using the residuals denoted by $[\tilde{\tau}_t = (\tilde{\tau}_{1t}, \tilde{\tau}_{2t'})']$. Based on this assumption, we are able to represent the modified data as depicted in Eq. (4). This representation considers the complex interdependencies reflected in the covariance matrix, laying the groundwork for subsequent examination and understanding of the data within the framework of our chosen model.

$$
y_t^* = y_t - \widetilde{\upsilon_{12}} \widetilde{\Theta_{22}}^{-1} \widetilde{\Psi_{22}}. \tag{4}
$$

In our study, the term for bias correction, crucial for refining our model, is detailed in Eq. (5). This component is essential for enhancing the accuracy and dependability of our results, as it compensates for possible biases encountered during the estimation phase.

$$
\lambda_{12}^* = \lambda_{12} - \widetilde{\upsilon_{12}} \widetilde{\Theta_{22}}^{-1} \widetilde{\Psi_{22}}. \tag{5}
$$

Therefore, the formulation of the fully modified ordinary least-squares estimator, pivotal to our analysis, is encapsulated in Eq. (6). This estimator is integral to refining our estimations, as it addresses potential issues of serial correlation and endogeneity within our regression models. By employing the fully modified ordinary least-squares method, we gain a more accurate and

Table 1 Descriptive statistical analysis.

Panel A: Statistical analysis of variable description

Statistics & variable	ex	fdi	ec	lab	tec	kn	ed
Mean	2.226	0.241	2.276	2.791	0.997	4.012	0.907
Maximum	3.737	0.591	3.381	3.557	2.245	5.301	1.062
Minimum	0.457	0.069	0.497	1.492	0.453	2.096	0.845
Standard deviation	0.085	0.117	0.572	0.315	0.441	1.506	0.217

Panel B: Correlation matrices

Variable	ex	fdi	ec	lab	tec	kn	ed
ex	1.000 (–)						
fdi	0.707** (2.056)	1.000 (–)					
ec	0.508*** (8.494)	0.164 (1.085)	1.000 (–)				
lab	0.458*** (8.505)	0.241* (1.947)	0.376*** (7.133)	1.000 (–)			
tec	0.617*** (9.005)	0.145 (1.234)	0.147*** (6.811)	0.211*** (9.284)	1.000 (–)		
kn	0.389*** (3.185)	0.146 (1.085)	0.149 (1.376)	0.167 (1.507)	0.284* (1.707)	1.000 (–)	
ed	0.284 (4.384)	0.114 (1.409)	0.206 (1.343)	0.098 (1.464)	0.229* (1.748)	0.177* (1.898)	1.000 (–)

* 10% significance level; ** 5% significance level; *** 1% significance level; T-statistics shown in parentheses.

insightful comprehension of the relationships present in our dataset.

$$\tilde{\varphi} = \begin{bmatrix} \tilde{\beta} \\ \tilde{\gamma}_1 \end{bmatrix} = \left(\sum_{t=1}^{T} \cdot \Sigma_t \cdot \Sigma t \right)^{-1} \left(\sum_{t=1}^{T} Z_t y_t^* - T \begin{bmatrix} \widetilde{\lambda_{12}^{*}}' \\ 0 \end{bmatrix} \right) \quad (6)$$

In Eq. (6), $Z_t = (y_t' D_t')$. Developing estimators for the long-term covariance matrix, a critical component in the implementation of fully modified ordinary least squares, is highlighted in studies by Atil et al. (2023), Wagner (2023), Phillips and Kheifets (2024), and Pelagatti and Sbrana (2024). This process is essential for the precision and efficacy of the fully modified ordinary least-squares approach. It entails refining the OLS regression by including both preceding and subsequent factors, ensuring that the error component in Eq. (1) remains uncorrelated with the entire historical sequence of random regressor variations. This method, as detailed in the research by Mark and Sul (2003), Panopoulou and Pittis (2004), Bruns et al. (2021), and Wang et al. (2024), is efficiently captured in Eq. (7).

$$y_t = x_t'\beta + D_{1t}'\gamma_t + \sum_{j=-q}^{r} \Delta X_{t+j}'\delta + \tau_{1t} \quad (7)$$

By incorporating q lags and r leads of the differenced regressors, the persistent correlation between variables τ_{1t} and τ_{2t} is effectively neutralized. This adjustment allows the estimation of $\varphi = (\beta', \gamma')'$ through the least-squares estimator to align with the asymptotic distribution achieved via the fully modified ordinary least-squares method. These methods are notably effective, as emphasized by Bai et al. (2021), Chebrolu et al. (2021), De Menezes et al. (2021), Zhao et al. (2022), and Bollen et al. (2022), in overcoming challenges like endogeneity, serial correlation, and biases that are typically prevalent in studies with smaller sample sizes.

Empirical results

Descriptive statistical analysis. For the purpose of this study, data extraction was conducted, harnessing information from 31 distinct provincial datasets covering the temporal bracket of 2005–2022. This compilation was sourced directly from the authoritative National Bureau of Statistics of China, ensuring data authenticity and integrity. An initial stage of rigorous analytical procedures was executed, encompassing both qualitative descriptive statistical evaluations and quantitative correlation analyses. This served to provide a holistic view of the data landscape, enabling the identification of patterns and inter-variable relationships. The culminating findings from this

analytical phase are methodically tabulated in Table 1. For clarity and comprehensive representation, the results are segmented into two distinct panels: Panel A elucidates the statistical analysis of variable description, while Panel B delineates the correlation matrices.

Within Panel A of Table 2, an examination of the data yields insights into provincial economic dynamics. The export trade registers an average value of 2.226, complemented by a notably narrow standard deviation of 0.085. This suggests a trend of ascent in export trade across the majority of provinces. Conversely, the foreign direct investment landscape, with a mean of 0.241 and a slightly more dispersed standard deviation of 0.117, indicates a predominant trajectory of foreign direct investment enhancement among provinces, albeit with some variability. E-commerce, represented by a mean of 2.276, portrays a positive trend; however, its relatively expansive standard deviation of 0.572 implies a diverse range of advancements and perhaps volatility within this sector. This is emblematic of the rapidly evolving and heterogeneous landscape of e-commerce in China, a reflection that aligns with empirical observations on the nation's digital commerce forefront. The labor resource endowment is quantified with a mean of 2.791 and a standard deviation of 0.315, providing insights into a generally favorable labor capital across provinces. The metrics for technological investment, with an average of 0.997 and a standard deviation of 0.441, underline the ongoing endeavors in technological innovation but also hint at disparities in the extent and pace of such investments across the provinces. Finally, the metric for knowledge capital is calculated with an average value of 4.012 and a standard deviation of 1.506. Meanwhile, the education level is measured, showing an average value of 0.907 and a standard deviation of 0.217.

In the wake of conducting a correlation analysis, the subsequent findings are articulated in Panel B of Table 1. An inaugural examination of the data reveals a discernible positive relationship between foreign direct investment and e-commerce relative to the scope of China's provincial export trade. Parallel to this, a deeper analytical traverse into the data underscores a tangible connection between labor resource endowment and technological forays as pivotal determinants of export trajectories. This interrelationship accentuates the premise that provinces emphasizing sustainable labor methodologies and avant-garde technological endeavors are not solely shaping a resilient economic structure but are concurrently enhancing their export trade capacities. This synergy between sustainability-oriented strategies and burgeoning trade volumes fortifies the argument

Table 2 Results of the effects of foreign direct investment and e-commerce on export trade.

Variable and model	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
fdi	0.287*** (5.723)	0.269*** (5.479)	0.228*** (5.606)	0.233*** (5.223)	0.209*** (5.517)
ec	0.489** (2.117)	0.481** (2.186)	0.491*** (2.708)	0.439*** (2.911)	0.405** (2.014)
lab	0.797** (2.275)	0.794** (1.982)	0.771** (2.338)	0.761** (2.264)	0.715** (2.389)
tec	0.346* (1.781)	0.335* (1.652)	0.312* (1.883)	0.308* (1.789)	0.304* (1.722)
kn	0.096 (1.428)	0.091 (1.038)	0.086* (1.646)	0.085 (1.498)	0.083* (1.187)
ed	0.152*** (2.616)	0.145** (2.058)	0.132** (2.004)	0.107** (2.301)	0.101** (2.154)
c	−2.589 (−1.039)	−2.134* (−1.642)	−2.684 (−1.324)	−2.172 (−1.451)	−2.107* (−1.749)
Chow test	74.162***				
Hausman test		$\chi^2 = 98.136$***			
F-statistical value	205.469***	191.316***	163.365***	160.412***	103.837***
Province-fixed effect		No	Yes	No	Yes
Year-fixed effect		No	No	Yes	Yes
R^2	0.575	0.488	0.559	0.437	0.412

* 10% significance level; ** 5% significance level; *** 1% significance level; T-statistics shown in parentheses; c constant.

that sustainability stands as a potent stimulant, accentuating both foreign direct investment and e-commerce outcomes. Furthermore, the analysis essentially establishes a positive correlation between knowledge capital, education level, and the export trade of China's provinces.

Results

In this investigation, a quintet of econometric techniques is deployed to discern the nuanced impacts of foreign direct investment and e-commerce on export trade. These methodologies encompass pooled ordinary least squares (Model 1), panel ordinary least squares (Model 2), province-specific fixed effects (Model 3), year-fixed effects (Model 4), and a provincial and year-fixed-effects approach integrating both provincial and annual dimensions (Model 5). The outcomes of these estimations are documented in Table 2. Upon evaluating the data through the prism of the Chow test, we discerned a clear rejection of the null hypothesis, indicating the inadequacy of pooled ordinary least squares for this dataset. Subsequent to this, the Hausman test was executed, which further rejected the null hypothesis, rendering the province-fixed effect model suboptimal. The decision to employ Model 5—integrating both province- and year-fixed effects—is grounded in several advanced econometric postulations. Kropko and Kubinec (2020), Hill et al. (2020), and Fernández-Val and Weidner (2018) posited that in the presence of unobserved heterogeneity—factors that remained constant over time but vary across entities or vice versa—implementing province- and year-fixed effects can yield unbiased and consistent estimators. This became particularly salient when considering phenomena such as global economic oscillations or overarching regulatory changes, which exerted a consistent impact across all provinces. By accounting for these twin axes of variability, Model 5 ensures the extrication of extraneous influences from the core relationship between foreign direct investment, e-commerce, and export trade. This approach enhances the robustness of the analysis, fortifying the validity of causal extrapolations drawn from the empirical results.

In Table 2, our primary focus is on the insights garnered from Model 5. However, it is crucial to recognize the crucial role that the outcomes of the additional four models played. These models act as a robustness check, lending further credibility to our main findings. Model 5's empirical data highlights a robust and statistically significant link between the surge in foreign direct investment and the increase in export trade within Chinese provinces. Specifically, a 1% increase in foreign direct investment inflows is associated with a 0.209% rise in provincial export trade volume. Shifting our analysis to the impact of e-commerce on the

export landscape of Chinese provinces, we observe a compelling dynamic. E-commerce is identified as a significant driver of export growth. Quantitatively speaking, a 1% growth in e-commerce activities results in a 0.405% increase in provincial export volumes. Moreover, our research identifies critical factors influencing export patterns in Chinese provinces, notably labor resources and technological investments. The study reveals that a 1% elevation in labor resource availability correlates with a 0.715% increment in export volumes at the provincial level. In the same vein, a 1% rise in technological investments is linked to a 0.304% boost in exports. Additionally, the study brings to light the constructive effects of knowledge capital and education levels on provincial export trade. An increase of 1% in these variables is found to enhance export volumes by 0.083% and 0.101%, respectively.

Discussion

The positive correlation between foreign direct investment inflows and increased export trade can be understood through various theoretical frameworks and empirical studies. Drawing on the research of Adikari et al. (2021), Rehman et al. (2023), and Zhang and Chen (2020), the eclectic paradigm suggests that foreign direct investment promotes export trade by transferring advanced technologies, managerial expertise, and marketing skills to the host country. These spillover effects enhance the competitiveness of domestic firms, boosting their export potential. Additionally, foreign direct investment helps to establish export-oriented industries within host economies, as seen in China's Special Economic Zones, which act as production and export hubs (Chiang and De Micheaux, 2022; Ngoc et al., 2022; Huang et al., 2023; Vukmirović et al., 2021). This influx of capital, technology, and knowledge through foreign direct investment acts as a catalyst, creating a trade-friendly environment and aligning provinces with a more globally integrated economic path. Several factors support e-commerce's positive impact on provincial export volumes. Firstly, e-commerce reduces informational disparities, fostering a transparent market conducive to robust exports. Additionally, as e-commerce platforms grow, their value proposition to users strengthens, encouraging an environment ripe for increasing transactions, including exports. Thirdly, e-commerce inherently reduces transactional friction, enabling businesses to engage more effectively in international trade. The theories and results of researchers like Onjewu et al. (2022), who contend that e-commerce lowers traditional trade barriers and enables even small businesses to participate in global markets, support this viewpoint. Lipton et al. (2018) and Fritz et al. (2004) show that online platforms allow businesses to overcome

geographic limitations, thus expanding their export reach. Tolstoy et al. (2021) and Zhong et al. (2022) discuss how e-commerce's digital footprint lessens the constraints of geographical distance, creating a more fluid international trade environment. Khan and Khan (2021) and Watson et al. (2018) illustrate how digital trade avenues boost export growth by adapting to market changes and consumer preferences. Additionally, Xi et al. (2023) and Deng et al. (2023) highlight the relationship between digital infrastructures and export portfolio diversification, with e-commerce spurring product innovation and differentiation. In conclusion, the integration of these theoretical insights and empirical evidence underlines the significant role of e-commerce as a key driver in enhancing the scale of export trade in Chinese provinces.

Labor resources and technological investments have been identified as key factors positively influencing the scale of export trade in Chinese provinces. This result is consistent with the Heckscher–Ohlin theorem, which states that regions typically export goods that effectively use their most abundant resources, according to research from Kunroo and Ahmad (2023) and Akther et al. (2022). Given China's substantial labor force, provinces endowed with richer labor resources are naturally capable of higher production, thereby supporting larger export volumes. Conversely, the relationship between technological investments and the strength of exports is anchored in contemporary economic growth theories, particularly those emphasizing the role of technology in economic development. Aghion et al. (1998) reinforce this notion, demonstrating that technological investment in regions not only enhances productivity but also provides a competitive advantage in international markets, thus boosting export capacity. Moreover, the study finds that both knowledge capital and education levels positively impact the scale of export trade in Chinese provinces. This underscores the importance of intellectual resources and educational attainment as drivers of export dynamics in a rapidly evolving economy like China's. The correlation with knowledge capital reflects China's strategic emphasis on innovation and intellectual property. Liu et al. (2017) emphasize that investments in research and development, especially in technology and sciences, have significantly enhanced China's export capabilities, leading to an increase in patents and technological breakthroughs. Due to these advancements, Chinese products now have a competitive advantage in the global market with higher value and higher quality. Similarly, the significance of education in boosting export trade is notable. Yang (2012) points out that China's focus on higher education and vocational training has equipped its workforce with the necessary skills for export-oriented industries, facilitating the production of more sophisticated, high-value products. Chen et al. (2022) further discuss how the synergy between technological advancement and educational development contributes to a more dynamic and diversified export sector. This interplay is vital for China's ability to adapt to global economic changes and more effectively participate in international trade. In conclusion, the increase in exports due to heightened knowledge capital and education levels signifies China's strategic transition towards a knowledge-based economy. This shift is reshaping the structure of its domestic industries and redefining China's role and competitiveness in the global market.

Robustness test. In this study, meticulous measures were taken to guarantee both the accuracy and reliability of the results, especially those obtained from the analysis using the province and year-fixed effect models. To ensure the dependability of our findings, an extensive robustness check was conducted on the outcomes of the province and year-fixed effect model. This

Table 3 Results of robustness test.

Variable and model	Fully modified ordinary least squares	Dynamic ordinary least squares
fdi	0.351*** (6.153)	0.368*** (6.231)
ec	0.478*** (3.784)	0.471*** (3.691)
cv	Yes	Yes
Test 1	0.061***	0.075***
Test 2	5.536***	5.572***
c	−2.461** (−2.133)	−2.505* (−1.778)
R^2	0.829	0.821

* 10% significant level; ** 5% significant level; *** 1% significant level; *t*-statistical value shown in parentheses; cv control variable; c constant (Test 1: In our co-integration examination, we adopted the Hansen parameter instability test. This test operates under the null hypothesis, which assumes the presence of co-integration within the time series data, a concept supported by the findings of Stojanovic et al. (2020), Winkler et al. (2014), and Zhang and Zhang (2014); Test 2—To evaluate the data's normality, we conducted the Jarque–Bera test, which operates on the null hypothesis that posits a normal distribution of the residuals).

involved the use of two econometric techniques: fully modified ordinary least squares and dynamic ordinary least squares. The implementation of fully modified ordinary least squares and dynamic ordinary least squares was critical in substantiating the integrity of the inferences drawn from the province and year-fixed effect model. The employment of these methods not only bolsters the solidity of our results but also reflects a commitment to the best standards of empirical rigor and methodological thoroughness. This approach to data verification underlies the credibility and trustworthiness of our conclusions. The specifics of these findings are systematically outlined in Table 3.

Table 3 presents a detailed evaluation of the estimated parameters, focusing on both their magnitude and statistical significance. Remarkably, the findings obtained through the application of fully modified ordinary least squares and dynamic ordinary least squares align closely with those from the initial province and year-fixed effect model. This alignment between fully modified ordinary least squares and dynamic ordinary least squares, in comparison to the province and year-fixed effect model, robustly confirms the accuracy of the original model. The consistency observed across these varied econometric methods not only strengthens the trustworthiness of the province and year-fixed effect model but also substantiates the reliability of the study's overall findings. The convergence of results across these methodologies indicates that the initial province and year-fixed effect model was meticulously crafted and successfully captured the essential dynamics of the variables under examination. The adoption of this comprehensive cross-validation process, which incorporates multiple analytical techniques, reinforces the solidity and validity of the research's conclusions. This multi-faceted approach to analysis assures a high level of confidence in the integrity and reliability of the study's results.

Regional heterogeneity analysis. Spanning a considerable geographical expanse, China is officially categorized into three distinct regional demarcations: eastern, central, and western. The eastern precinct is widely acknowledged as the epitome of China's developmental zenith, encapsulating its most economically advanced locales. Conversely, the central sector is recognized for its intermediary developmental status, while the western swathes are often delineated by developmental lacunae. These territories, though unified under a single nationhood, manifest disparate attributes ranging from their economic growth trajectories, state-directed policy nuances, and infrastructural development gradients to their inherent geographical peculiarities. To delve into the multifaceted influence of foreign direct investment and e-commerce on regional export dynamics, our empirical

Table 4 Results of regional heterogeneity analysis.

Variable and model	Model (7)	Model (8)	Model (9)
fdi	0.278*** (4.328)	0.179*** (4.586)	0.161*** (4.179)
ec	0.397** (2.167)	0.365** (2.187)	0.325** (2.019)
cv	Yes	Yes	Yes
c	−1.507 (−1.259)	−1.547* (−1.624)	−1.701 (−1.213)
F-statistical value	79.977***	74.728***	75.363***
Province-fixed effect	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes
R^2	0.396	0.361	0.318
Area	Eastern area	Central area	Western area

* 10% significance level; ** 5% significance level; *** 1% significance level; Standard error shown in parentheses; cv control variable.

approach disaggregated the core dataset, structuring it into three region-specific sub-samples. This strategic bifurcation aimed at discerning the variable intensities of foreign direct investment and e-commerce influences across these heterogeneous regions. The analytical outcomes derived from this region-centric examination are detailed in Table 4.

Reflected in Table 4, the repercussions of foreign direct investment on export trade reveal intricate regional gradations within China's geographical tapestry. Concretely, a marginal ascent of 1% in foreign direct investment is associated with a 0.278% enhancement in the export dynamism of the eastern provinces. This increment tapers to 0.179% for central provinces and further diminishes to 0.161% for their western counterparts. The scholarly discourses of Contractor et al. (2020), Dang and Zhao (2020), and Batschauer da Cruz et al. (2022) elucidated that the synergy between foreign direct investment and export growth hinged upon a triad of factors: intrinsic firm capabilities, locational attributes, and the operational modus operandi. The eastern provinces, historically recognized as China's economic epicenter, are imbued with a robust infrastructural matrix, streamlined trade corridors, and a business milieu that gravitates towards global market integration. These intrinsic locational advantages, complemented by the spatial competition theory proposed by Proost and Thisse (2019), Redding and Rossi-Hansberg (2017), and Goerzen et al. (2013), amplify the efficacy of foreign direct investment in spurring export trade. On the contrary, the central belt, despite its ascending economic trajectory, is intermittently stymied by transitional economic impediments, occasionally attenuating the foreign direct investment-export nexus. The western provinces, albeit burgeoning, still navigate developmental constraints, resonating with Wang and Zhao (2015) and Jiang et al. (2016)'s backwash effects, wherein peripheral regions grapple to harness the complete spectrum of foreign direct investment benefits. From a sustainability lens, echoing the tenets of Milne and Gray's (2013) Triple Bottom Line framework, the magnitude and mode of foreign direct investment's assimilation should be judiciously balanced to ensure economic, social, and environmental equanimity. The immediate economic impetus observed, particularly in the eastern provinces, warrants an integrated approach wherein foreign direct investment infusion aligns with sustainable practices, ensuring that regional development dovetails with ecological stewardship and socio-cultural inclusivity. Such a harmonized trajectory ensures that the fruits of foreign direct investment are not ephemeral but perennial, fostering a resilient and sustainable export landscape across all regions.

Referring to the results presented in Table 4, an augmentation of 1% in e-commerce transaction volume is observed to lead to a differentiated impact on the export trade across China's tripartite regional structure: specifically, a surge of 0.397% in the eastern provinces, an enhancement of 0.365% in the central provinces, and a growth of 0.325% in the western provinces. This regional heterogeneity in the influence of e-commerce on export trade can be supported by a confluence of academic perspectives and established theoretical underpinnings. Drawing insights from Porter, Michael's (2011) Competitive advantage theory, the eastern provinces, having established themselves as economic powerhouses, have already harnessed advanced infrastructural frameworks and digital ecosystems. This enables them to efficiently leverage the capabilities of e-commerce, thereby reflecting a more pronounced augmentation in their export trade. The central provinces, as highlighted by North and Douglass's (1989) theory of institutional change, are navigating through evolving institutional landscapes, mediating between traditional trade mechanisms and burgeoning digital frontiers. While they have made significant strides, the transformational gaps that exist temper the full realization of e-commerce benefits in the domain of exports. The western provinces, on the other hand, are still grappling with foundational challenges. Drawing from Sachs and Warner's (2001) resource curse hypothesis, these provinces, abundant in natural resources, might have historically focused more on primary sectors, leading to a lag in the adoption and integration of e-commerce into their economic tapestry. This could partially elucidate the relatively muted growth in export trade from e-commerce advancements. Incorporating the sustainability ethos, as expounded in the triple bottom line approach by Elkington (1998), the expansion of e-commerce should not merely serve economic objectives. It should be orchestrated in a manner that respects ecological boundaries and promotes social inclusivity. Especially in regions like the western provinces, where development is paramount, it is critical to ensure that the surge in e-commerce-driven exports is not at the expense of environmental degradation or social disparities, thereby upholding a balanced, sustainable developmental trajectory.

Conclusions

Amidst the fast-paced evolution of the global economy, key factors such as foreign direct investment and e-commerce have become instrumental in reshaping China's export sector between 2005 and 2022. Our analytical models, which utilize a combination of province- and year-fixed effects analysis along with fully modified ordinary least squares and dynamic ordinary least-squares methodologies, shed light on how foreign direct investment and e-commerce synergistically enhance China's export capabilities. Significantly, this expansion in China's exports aligns with the global agenda for sustainable development. It's encouraging to see that China's growth in exports extends beyond the realms of international investment and digital marketplaces, intertwining sustainable practices like optimizing local labor

resources and prioritizing technological advancements. These approaches contribute to a more sustainable export environment. Our findings further reveal that variables such as knowledge capital and educational levels positively influence China's export figures. Additionally, our analysis of regional disparities provides a deeper understanding. The eastern regions of China show greater responsiveness to foreign direct investment and e-commerce in driving export trade, whereas the western regions respond more modestly. This variation highlights the need for tailored policies and sustainability strategies to ensure a fair distribution of the benefits from foreign direct investment and e-commerce across all regions. In conclusion, while foreign direct investment and e-commerce are key drivers of China's export growth, the broader story is one of sustainable development. Technological innovation and human capital development are pivotal to China's continued success in exports. Moving forward, it is essential for policymakers to maintain a careful equilibrium between these economic drivers and sustainable development goals, fostering a balance between economic growth and environmental sustainability.

Drawing upon the insights derived from this study, we elucidate several policy recommendations along with practical solutions. First, for policymakers and business leaders, investing in technology and education is identified as a crucial strategy. The significant impact of technological innovation and a well-educated workforce on export growth underscores the necessity for ongoing investment in these domains. For academia, this opens avenues for further research into specific types of educational programs and technological innovations that most effectively enhance export capabilities. Businesses, especially in the export sector, should prioritize employee training and the adoption of cutting-edge technologies to maintain competitiveness. Second, considering the varied responsiveness to foreign direct investment and e-commerce between China's eastern and western regions, it's imperative for regional authorities and business managers to customize their policies and strategies to suit the unique needs and strengths of their regions. This could involve targeted investments in infrastructure and digital capabilities in the eastern regions while simultaneously focusing on cultivating other competitive advantages in the western regions. Academia can play a role by conducting region-specific research to identify the most effective strategies for each area. Third, the intersection of export growth with sustainable development goals necessitates a comprehensive approach to policymaking. Managers in the export sector are encouraged to integrate sustainable practices into their business models, such as the utilization of environmentally friendly technologies and adherence to fair labor practices. This area also presents an opportunity for academic research into the effective implementation of sustainable practices in the export sector, aiming to balance profitability and competitiveness. Finally, our findings suggest that although foreign direct investment and e-commerce are significant drivers of export growth, their benefits are not uniformly experienced across all regions. This indicates the need for balanced development strategies that ensure equitable benefits from foreign direct investment and e-commerce across various regions. Strategies might include enhancing e-commerce infrastructure in less-developed areas or offering incentives for foreign investment in regions currently less engaged with these investments. For academics, this highlights the necessity of researching ways to optimize the impact of foreign direct investment and e-commerce across diverse regions, promoting equitable economic growth. These policy implications offer a strategic roadmap for leveraging key drivers of export growth in China, highlighting the importance of regional customization, sustainable development, and balanced economic strategies.

In the course of this research, certain limitations emerged that warrant acknowledgment. Firstly, the study's timeframe, spanning from 2005 to 2022, may not fully capture the evolving dynamics of foreign direct investment and e-commerce in the context of China's longer-term economic history. A more expansive temporal analysis could provide deeper historical insights. Secondly, while the fully modified ordinary least squares and dynamic ordinary least-squares methodologies and fixed effect models offer robustness, they may not encompass all the nuanced intricacies of the interactions between the chosen variables. Future research could employ mixed-method approaches, blending quantitative and qualitative inquiries to attain a richer understanding. Thirdly, our focus on regional heterogeneity, while pivotal, may overlook intra-regional variances that can significantly influence export trends. Subsequent studies might delve deeper into micro-level analyses, probing district- or city-level data. Fourthly, the emphasis on sustainability, though aligned with global imperatives, is predominantly viewed through the lenses of labor and technology. Incorporating other sustainability metrics, such as environmental or social indicators, could render a holistic view. Lastly, the external validity of our findings, primarily centered on China, might be limited in their generalizability to other nations. Comparative studies juxtaposing China's experiences with those of other global players could bridge this gap. Addressing these limitations would not only refine the existing body of knowledge but also ensure a more comprehensive alignment of economic strategies with sustainable development goals.

Data availability

All data generated or analyzed during this study are included in this published article.

References

Abdul-Rahim R, Bohari SA, Aman A, Awang Z (2022) Benefit–risk perceptions of FinTech adoption for sustainability from bank consumers' perspective: the moderating role of fear of COVID-19. Sustainability 14(14):8357, https://www.mdpi.com/2071-1050/14/14/8357

Adikari AMP, Liu H, Marasinghe MMSA (2021) Inward foreign direct investment-induced technological innovation in Sri Lanka? Empirical evidence using ARDL approach. Sustainability 13(13):7334, https://www.mdpi.com/2071-1050/13/13/7334

Agarwal J, Wu T (2015) Factors influencing growth potential of E-commerce in emerging economies: an institution-based N-OLI framework and research propositions. Thunderbird Int Bus Rev 57(3):197–215. https://doi.org/10.1002/tie.21694

Aghion P, Howitt P, Brant-Collett M, García-Peñalosa C (1998) Endogenous growth theory. MIT Press

Ahmed Z, Zafar MW, Ali S (2020) Linking urbanization, human capital, and the ecological footprint in G7 countries: an empirical analysis. Sustain Cities Soc 55:102064, https://www.sciencedirect.com/science/article/pii/S2210670720300512

Ahn SC, Thomas GM (2023) Likelihood-based inference for dynamic panel data models. Empir Econ 64(6):2859–2909. https://doi.org/10.1007/s00181-023-02375-0

Akther T, Voumik LC, Hasanur Rahman M (2022) The pattern of international trade between Bangladesh and USA: Heckscher–Ohlin and Rybczynski analysis. Mod Supply Chain Res Appl 4(3):162–176. https://doi.org/10.1108/MSCRA-03-2022-0011

Amornkitvikai Y, Tham SY, Harvie C, Writthym Buachoom W (2022) Barriers and factors affecting the e-commerce sustainability of Thai micro-, small-and medium-sized enterprises (MSMEs). Sustainability 14(14):8476, https://www.mdpi.com/2071-1050/14/14/8476

Antràs P, Alonso De Gortari, Itskhoki O (2017) Globalization, inequality and welfare. J Int Econ 108:387–412. https://www.sciencedirect.com/science/article/pii/S0022199617300958

Anzoategui D, Comin D, Gertler M, Martinez J (2019) Endogenous technology adoption and R&D as sources of business cycle persistence. Am Econ J 11(3):67–110. https://doi.org/10.1257/mac.20170269

Atil L, Fellag H, Sipols AE, Santos-Martín MT, De Blas CS (2023) Non-linear cointegration test, based on record counting statistic. Comput Econ https://doi.org/10.1007/s10614-023-10520-1

Atkin D (2016) Endogenous skill acquisition and export manufacturing in Mexico. Am Econ Rev 106(8):2046–2085. https://www.aeaweb.org/articles?id=10.1257/aer.20120901

Auboin M, Koopman R, Xu A (2021) Trade and innovation policies: coexistence and spillovers. J Policy Model 43(4):844–872. https://www.sciencedirect.com/science/article/pii/S0161893821000375

Autor DH, Dorn D, Hanson GH (2015) Untangling trade and technology: evidence from local labour markets. Econ J 125(584):621–646. https://academic.oup.com/ej/article-abstract/125/584/621/5077881

Bai J, Choi SH, Liao Y (2021) Feasible generalized least squares for panel data with cross-sectional and serial correlations. Empir Econ 60(1):309–326. https://doi.org/10.1007/s00181-020-01977-2

Baltagi BH (2021) Econometric analysis of panel data. Springer texts in business and economics. Springer International Publishing, Cham

Banalieva ER, Dhanaraj C (2019) Internalization theory for the digital economy. J Int Bus Stud 50(8):1372–1387. https://doi.org/10.1057/s41267-019-00243-7

Batschauer da Cruz, Beatriz C, Eliete Floriani D, Amal M (2022) The OLI paradigm as a comprehensive model of FDI determinants: a sub-national approach. Int J Emerg Mark 17(1):145–176. https://www.emerald.com/insight/content/doi/10.1108/IJOEM-07-2019-0517/full/html

Bhaumik, Kumar S, Driffield N, Zhou Y (2016) Country specific advantage, firm specific advantage and multinationality—sources of competitive advantage in emerging markets: evidence from the electronics industry in China. Int Bus Rev 25(1):165–176. https://www.sciencedirect.com/science/article/pii/S0969593115000050

Blanchard EJ, Olney WW (2017) Globalization and human capital investment: export composition drives educational attainment. J Int Econ 106:165–183. https://www.sciencedirect.com/science/article/pii/S0022199617300302

Blanchard, Jean-Marc F (2019) Brazil's Samba with China: economics brought them closer, but failed to ensure their Tango. J Chin Political Sci 24(4):583–603. https://doi.org/10.1007/s11366-018-09586-8

Bollen KA, Fisher ZF, Giordano ML, Lilly AG, Luo L, Ye A (2022) An introduction to model implied instrumental variables using two stage least squares (MIIV-2SLS) in structural equation models (SEMs). Psychol Methods 27(5):752, https://psycnet.apa.org/record/2021-70427-001

Bruns SB, Moneta A, Stern DI (2021) Estimating the economy-wide rebound effect using empirically identified structural vector autoregressions. Energy Econ 97:105158, https://www.sciencedirect.com/science/article/pii/S0140988321000633

Castilho M, Menéndez M, Sztulman A (2012) Trade liberalization, inequality, and poverty in Brazilian states. World Dev 40(4):821–835. https://www.sciencedirect.com/science/article/pii/S0305750X11002403

Chebrolu N, Läbe T, Vysotska O, Behley J, Stachniss C (2021) Adaptive robust kernels for non-linear least squares problems. IEEE Robot Autom Lett 6(2):2240–2247. https://ieeexplore.ieee.org/abstract/document/9361339/

Chen H, Yan B, Fei R, Bao S (2023) Assessing the impact of trade policy uncertainty on pollution emissions: an analysis of Chinese firms' green transformation. Environ Sci Pollut Res 30(47):104577–104591. https://doi.org/10.1007/s11356-023-29778-x

Chen J, Hu X, Huang J, Lin R (2022) Market integration and green economic growth—recent evidence of China's city-level data from 2004–2018. Environ Sci Pollut Res 29(29):44461–44478. https://doi.org/10.1007/s11356-022-19070-9

Chiang M-H, De Micheaux EL (2022) China's outward foreign direct investment in Southeast Asia: analyzing the Chinese state's strategies and potential influence. Thunderbird Int Bus Rev 64(6):581–593. https://doi.org/10.1002/tie.22311

Choong C-K (2012) Does domestic financial development enhance the linkages between foreign direct investment and economic growth? Empir Econ 42(3):819–834. https://doi.org/10.1007/s00181-011-0455-2

Christou C, Pittis N (2002) Kernel and bandwidth selection, prewhitening, and the performance of the fully modified least squares estimation method. Econom Theory 18(4):948–961. https://www.cambridge.org/core/journals/econometric-theory/article/kernel-and-bandwidth-selection-prewhitening-and-the-performance-of-the-fully-modified-least-squares-estimation-method/9F28178B61EF30D406AC2ABDC0AECBC0

Chudik A, Pesaran MH (2015) Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. J Econ 188(2):393–420. https://www.sciencedirect.com/science/article/pii/S0304407615000767

Contractor FJ, Dangol R, Nuruzzaman N, Raghunath S (2020) How do country regulations and business environment impact foreign direct investment (FDI) inflows? Int Bus Rev 29(2):101640, https://www.sciencedirect.com/science/article/pii/S0969593118305997

Cordes DL, Marinova D (2023) Systematic literature review of the role of E-commerce in providing pathways to sustainability for poverty alleviation in sub-Saharan Africa. Discov Sustain 4(1):7. https://doi.org/10.1007/s43621-022-00109-3

Dang L, Zhao J (2020) Cultural risk and management strategy for Chinese enterprises' overseas investment. China Econ Rev 61:101433, https://www.sciencedirect.com/science/article/pii/S1043951X20300304

Darku AB (2021) International trade and income convergence: sorting out the nature of bilateral trade. Int J Financ Econ 26(4):5337–5348. https://doi.org/10.1002/ijfe.2068

De Menezes DQF, Prata DM, Secchi AR, Pinto JC (2021) A review on robust M-estimators for regression analysis. Comput Chem Eng 147:107254, https://www.sciencedirect.com/science/article/pii/S0098135421000326

Deng T, Khan MA, Uddin M, Haider A (2023) Connecting fiscal decentralization with climate change mitigation in China: directions for carbon capturing systems. Processes 11(3):712, https://www.mdpi.com/2227-9717/11/3/712

Duan W, Zhu S, Lai M (2020) The impact of COVID-19 on China's trade and outward FDI and related countermeasures. J Chin Econ Bus Stud 18(4):355–364. https://doi.org/10.1080/14765284.2020.1855395

Elia S, Giuffrida M, Mariani MM, Bresciani S (2021) Resources and digital export: an RBV perspective on the role of digital technologies and capabilities in cross-border e-commerce. J Bus Res 132:158–169. https://www.sciencedirect.com/science/article/pii/S0148296321002484

Elkington J (1998) Partnerships from cannibals with forks: the triple bottom line of 21st-century business. Environ Qual Manag 8(1):37–51. https://doi.org/10.1002/tqem.3310080106

Fernández-Val I, Weidner M (2018) Fixed effects estimation of large-T panel data models. Annu Rev Econ 10(1):109–138. https://doi.org/10.1146/annurev-economics-080217-053542

Fidrmuc J, Korhonen I (2010) The impact of the global financial crisis on business cycles in Asian emerging economies. J Asian Econ 21(3):293–303. https://www.sciencedirect.com/science/article/pii/S1049007809000657

Fingleton B (2023) Estimating dynamic spatial panel data models with endogenous regressors using synthetic instruments. J Geogr Syst 25(1):121–152. https://doi.org/10.1007/s10109-022-00397-3

Fritz M, Hausen T, Schiefer G (2004) Developments and development directions of electronic trade platforms in US and European agri-food markets: impact on sector organization. Int food Agribus Manag Rev 7(1030-2016–82569):1–21. https://ageconsearch.umn.edu/record/8146/

Fu X, Woo WT, Hou J (2016) Technological innovation policy in China: the lessons, and the necessary changes ahead. Econ Change Restruct 49(2–3):139–157. https://doi.org/10.1007/s10644-016-9186-x

Gao H (2018) Digital or trade? The contrasting approaches of China and US to digital trade. J Int Econ Law 21(2):297–321. https://academic.oup.com/jiel/article-abstract/21/2/297/4996884

Giuffrida M, Mangiaracina R, Perego A, Tumino A (2017) Cross-border B2C e-commerce to Greater China and the role of logistics: a literature review. Int J Phys Distrib Logist Manag 47(9):772–795. https://www.emerald.com/insight/content/doi/10.1108/IJPDLM-08-2016-0241/full/html

Goerzen A, Asmussen CG, Nielsen BB (2013) Global cities and multinational enterprise location strategy. J Int Bus Stud 44(5):427–450. https://doi.org/10.1057/jibs.2013.11

Gorla N, Chiravuri A, Chinta R (2017) Business-to-business e-commerce adoption: an empirical investigation of business factors. Inf Syst Front 19(3):645–667. https://doi.org/10.1007/s10796-015-9616-8

Götz M (2020) Attracting foreign direct investment in the era of digitally reshaped international production. The primer on the role of the investment policy and clusters—the case of Poland. J East-West Bus 26(2):131–160. https://doi.org/10.1080/10669868.2019.1692985

Grübler A, O'Neill B, Riahi K, Chirkov V, Goujon A, Kolp P, Prommer I, Scherbov S, Slentoe E (2007) Regional, national, and spatially explicit scenarios of demographic and economic change based on SRES. Technol Forecast Soc Change 74(7):980–1029. https://www.sciencedirect.com/science/article/pii/S0040162506001454

Ha LT (2022) Are digital business and digital public services a driver for better energy security? Evidence from a European sample. Environ Sci Pollut Res 29(18):27232–27256. https://doi.org/10.1007/s11356-021-17843-2

Hanelt A, Bohnsack R, Marz D, Antunes Marante C (2021) A systematic review of the literature on digital transformation: insights and implications for strategy and organizational change. J Manag Stud 58(5):1159–1197. https://doi.org/10.1111/joms.12639

Hao S, Chen Z, Wang C-C, Hung C-Y (2023) Impact of digital service trade barriers and cross-border digital service inputs on economic growth. Sustainability 15(19):14547, https://www.mdpi.com/2071-1050/15/19/14547

Hartono, Gian P, Robiyanto Robiyanto (2023) Factors affecting the inconsistency of dividend policy using dynamic panel data model. SN Bus Econ 3(2):53. https://doi.org/10.1007/s43546-023-00431-6

He Y, Wu R, Choi Y-J (2021) International logistics and cross-border E-commerce trade: who matters whom? Sustainability 13(4):1745, https://www.mdpi.com/2071-1050/13/4/1745

Hill TD, Davis AP, Roos JM, French MT (2020) Limitations of fixed-effects models for panel data. Sociol Perspect 63(3):357–369. https://doi.org/10.1177/0731121419863785

Huang Y, Muhammad S, Raza F, Usman M (2023) Asymmetric role of natural resources dependence, industrialization, and foreign direct investment in China's economic growth. Resour Policy 85:103932, https://www.sciencedirect.com/science/article/pii/S0301420723006438

Jiang X, Zhang L, Xiong C, Wang R (2016) Transportation and regional economic development: analysis of spatial spillovers in China provincial regions. Netw Spat Econ 16(3):769–790. https://doi.org/10.1007/s11067-015-9298-2

Jin G, Huang Z (2023) Asymmetric influence of China's outward FDI and exports on trade-adjusted resources footprint in belt and road node countries: moderating role of governance. Resour Policy 82:103558, https://www.sciencedirect.com/science/article/pii/S0301420723002696

Jones CI (2019) Paul Romer: ideas, nonrivalry, and endogenous growth. Scand J Econ 121(3):859–883. https://doi.org/10.1111/sjoe.12370

Katz R, Callorda F (2018) Accelerating the development of Latin American digital ecosystem and implications for broadband policy. Telecommun Policy 42(9):661–681. https://www.sciencedirect.com/science/article/pii/S0308596117302914

Khan H, Khan Z (2021) The efficacy of marketing skills and market responsiveness in marketing performance of emerging market exporting firms in advanced markets: the moderating role of competitive intensity. Int Bus Rev 30(6):101860, https://www.sciencedirect.com/science/article/pii/S0969593121000676

Kheifets IL, Phillips PCB (2023) Fully modified least squares cointegrating parameter estimation in multicointegrated systems. J Econ 232(2):300–319. https://www.sciencedirect.com/science/article/pii/S030440762100186X

Klimenko M, Qu J (2023) Global Digital Platforms, technology transfer and foreign direct investment policies in two-sided markets. Econ Inq 61(3):584–604. https://doi.org/10.1111/ecin.13132

Kripfganz S, Sarafidis V (2021) Instrumental-variable estimation of large-T panel-data models with common factors. Stata J 21(3):659–686. https://doi.org/10.1177/1536867X211045558

Kropko J, Kubinec R (2020) Interpretation and identification of within-unit and cross-sectional variation in panel data models. PLoS ONE 15(4):e0231349, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0231349

Kunroo MH, Ahmad I (2023) Heckscher–Ohlin theory or the modern trade theory: how the overall trade characterizes at the global level? J Quant Econ 21(1):151–174. https://doi.org/10.1007/s40953-022-00330-x

Kwak J, Zhang Y, Yu J (2019) Legitimacy building and e-commerce platform development in China: the experience of Alibaba. Technol Forecast Soc Change 139:115–124. https://www.sciencedirect.com/science/article/pii/S0040162518309636

Lei T, Xie P (2023) Fostering enterprise innovation: the impact of China's pilot free trade zones. J Knowl Econ https://doi.org/10.1007/s13132-023-01501-8

Li F, Frederick S, Gereffi G (2019) E-Commerce and industrial upgrading in the Chinese apparel value chain. J Contemp Asia 49(1):24–53. https://doi.org/10.1080/00472336.2018.1481220

Li K, Kim DJ, Lang KR, Kauffman RJ, Naldi M (2020) How should we understand the digital economy in Asia? Critical assessment and research agenda. Electron Commer Res Appl 44:101004, https://www.sciencedirect.com/science/article/pii/S1567422320300818

Li K, Cui G, Lu L (2020) Efficient estimation of heterogeneous coefficients in panel data models with common shocks. J Econ 216(2):327–353. https://www.sciencedirect.com/science/article/pii/S0304407619302222

Li R, Liu Y, Bustinza OF (2019) FDI, service intensity, and international marketing agility: the case of export quality of Chinese enterprises. Int Mark Rev 36(2):213–238. https://www.emerald.com/insight/content/doi/10.1108/IMR-01-2018-0031/full/html

Li Y, He Y, Wu R (2023) Traversing the macroeconomic terrain: an exploration of South Korea's economic responsiveness to cross-border e-commerce production technology alterations in the global arena. Sustainability 15(15):11719, https://www.mdpi.com/2071-1050/15/15/11719

Lin J, Luo Z, Luo X (2020) Understanding the roles of institutional pressures and organizational innovativeness in contextualized transformation toward e-business: evidence from agricultural firms. Int J Inf Manag 51:102025, https://www.sciencedirect.com/science/article/pii/S0268401219301896

Lipton A, Hardjono T, Pentland A (2018) Digital Trade Coin: towards a more stable digital currency. R Soc Open Sci 5(7):180155. https://doi.org/10.1098/rsos.180155

Liu J, Xie J (2020) Environmental regulation, technological innovation, and export competitiveness: an empirical study based on China's manufacturing industry. Int J Environ Res Public Health 17(4):1427, https://www.mdpi.com/1660-4601/17/4/1427

Liu L, Moon HR, Schorfheide F (2020) Forecasting with dynamic panel data models. Econometrica 88(1):171–201. https://doi.org/10.3982/ECTA14952

Liu X, Schwaag Serger S, Tagscherer U, Chang AY (2017) Beyond catch-up—can a new innovation policy help China overcome the middle income trap? Sci Public Policy 44(5):656–669. https://academic.oup.com/spp/article-pdf/doi/10.1093/scipol/scw092/20917267/scw092.pdf

Lyu C, Peng C, Yang H, Li H, Gu X (2022) Social capital and innovation performance of digital firms: serial mediation effect of cross-border knowledge search and absorptive capacity. J Innov Knowl 7(2):100187, https://www.sciencedirect.com/science/article/pii/S2444569X22000270

Mahalik MK, Pal S, Le T-H, Mishra S (2023) Does environmental policy stringency improve nature's health in BRICS economies? Implications for sustainable development. Environ Sci Pollut Res 31(1):509–528. https://doi.org/10.1007/s11356-023-31134-y

Mansion SE, Bausch A (2020) Intangible assets and SMEs' export behavior: a meta-analytical perspective. Small Bus Econ 55(3):727–760. https://doi.org/10.1007/s11187-019-00182-5

Mark NC, Sul D (2003) Cointegration vector estimation by panel DOLS and long-run money demand*. Oxf Bull Econ Stat 65(5):655–680. https://doi.org/10.1111/j.1468-0084.2003.00066.x

Milne MJ, Gray R (2013) W(h)ither ecology? The triple bottom line, the global reporting initiative, and corporate sustainability reporting. J Bus Ethics 118(1):13–29. https://doi.org/10.1007/s10551-012-1543-8

Mohammad Shafiee M, Warkentin M, Motamed S (2023) Do human capital and relational capital influence knowledge-intensive firm competitiveness? The roles of export orientation and marketing knowledge capability. J Knowl Manag https://www.emerald.com/insight/content/doi/10.1108/JKM-11-2022-0921/full/html

Moon HR, Weidner M (2017) Dynamic linear panel regression models with interactive fixed effects. Econom Theory 33(1):158–195. https://www.cambridge.org/core/journals/econometric-theory/article/dynamic-linear-panel-regression-models-with-interactive-fixed-effects/CE84920C05BB652892D7B7659A1D5CD5

Ngoc PTB, Vu HQ, Long PD (2022) Domestic total factor productivity with trade and heterogenous foreign direct investment in developing countries: a case of Vietnamese manufacturing. Int J Emerg Mark. https://www.emerald.com/insight/content/doi/10.1108/IJOEM-08-2021-1333/full/html

Norkutė M, Sarafidis V, Yamagata T, Cui G (2021) Instrumental variable estimation of dynamic linear panel data models with defactored regressors and a multifactor error structure. J Econ 220(2):416–446. https://www.sciencedirect.com/science/article/pii/S0304407620301275

North, Douglass C (1989) Final remarks-institutional change and economic history. J Inst Theor Econ/Z Gesamt Staatswiss 238:45, https://www.jstor.org/stable/40751187

Onjewu A-KE, Hussain S, Haddoud MY (2022) The interplay of e-commerce, resilience and exports in the context of COVID-19. Inf Syst Front 24(4):1209–1221. https://doi.org/10.1007/s10796-022-10342-w

Otchere I, Soumaré I, Yourougou P (2016) FDI and financial market development in Africa. World Econ 39(5):651–678. https://doi.org/10.1111/twec.12277

Panopoulou E, Pittis N (2004) A comparison of autoregressive distributed lag and dynamic OLS cointegration estimators in the case of a serially correlated cointegration error. Econom J 7(2):585–617. https://academic.oup.com/ectj/article-abstract/7/2/585/5073337

Pedroni P (2001) Fully modified OLS for heterogeneous cointegrated panels. In: Baltagi BH, Fomby TB, Carter Hill R (eds) Nonstationary panels, panel cointegration, and dynamic panels. Emerald Group Publishing Limited, pp. 93–130

Pelagatti M, Sbrana G (2024) Estimating correlations among elliptically distributed random variables under any form of heteroskedasticity. Quant Finance 1–14. https://doi.org/10.1080/14697688.2023.2278502

Perrini F, Tencati A (2006) Sustainability and stakeholder management: the need for new corporate performance evaluation and reporting systems. Bus Strategy Environ 15(5):296–308. https://doi.org/10.1002/bse.538

Phang DCW, Wang K, Wang Q, Kauffman RJ, Naldi M (2019) How to derive causal insights for digital commerce in China? A research commentary on computational social science methods. Electron Commer Res Appl 35:100837, https://www.sciencedirect.com/science/article/pii/S1567422319300146

Phillips PCB, Kheifets IL (2024) High-dimensional IV cointegration estimation and inference. J Econ 238(2):105622, https://www.sciencedirect.com/science/article/pii/S030440762300338X

Porter ME (2011) Competitive advantage of nations: creating and sustaining superior performance. Simon and Schuster

Proost S, Thisse J-F (2019) What can be learned from spatial economics? J Econ Lit 57(3):575–643. https://doi.org/10.1257/jel.20181414

Qi X, Chan JH, Hu J, Li Y (2020) Motivations for selecting cross-border e-commerce as a foreign market entry mode. Ind Mark Manag 89:50–60. https://www.sciencedirect.com/science/article/pii/S0019850118308071

Qian Y, Liu J, Cheng Z, Forrest JY-L (2021) Does the smart city policy promote the green growth of the urban economy? Evidence from China. Environ Sci Pollut Res 28(47):66709–66723. https://doi.org/10.1007/s11356-021-15120-w

Redding SJ, Rossi-Hansberg E (2017) Quantitative spatial economics. Annu Rev Econ 9(1):21–58. https://doi.org/10.1146/annurev-economics-063016-103713

Rehman A, Radulescu M, Ahmad F, Kamran Khan M, Iacob SE, Cismas LM (2023) Investigating the asymmetrical influence of foreign direct investment, remittances, reserves, and information and communication technology on Pakistan's economic development. Econ Res-Ekonom Istraž 36(2):2131591. https://doi.org/10.1080/1331677X.2022.2131591

Rita P, Ramos RF (2022) Global research trends in consumer behavior and sustainability in E-Commerce: a bibliometric analysis of the knowledge structure. Sustainability 14(15):9455, https://www.mdpi.com/2071-1050/14/15/9455

Sachs JD, Warner AM (2001) The curse of natural resources. Eur Econ Rev 45(4–6):827–838. https://www.sciencedirect.com/science/article/pii/S0014292101001258

Shanmugalingam P, Shanmuganeshan A, Manorajan A, Kugathasan M, Pathirana GY (2023) Does e-commerce really matter on international trade of Asian countries: evidence from panel data. PLoS ONE 18(4):e0284503, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0284503

Singh S, Singh R (2022) Revisiting the debate on import-led substitution and export-led industrialization: where is India heading under self-reliant India? J World Trade 56(1). https://kluwerlawonline.com/journalarticle/Journal+of+World+Trade/56.5/TRAD2022005

Sinha A, Sengupta T, Alvarado R (2020) Interplay between technological innovation and environmental quality: formulating the SDG policies for next 11 economies. J Clean Prod 242:118549, https://www.sciencedirect.com/science/article/pii/S0959652619334195

Song M, Wang S (2018) Market competition, green technology progress and comparative advantages in China. Manag Decis 56(1):188–203. https://www.emerald.com/insight/content/doi/10.1108/MD-04-2017-0375/full/html

Stojanovic V, He S, Zhang B (2020) State and parameter joint estimation of linear stochastic systems in presence of faults and NON-GAUSSIAN noises. Int J Robust Nonlinear Control 30(16):6683–6700. https://doi.org/10.1002/rnc.5131

Sun L, Li,M X, Wang Y (2024) Digital trade growth and mineral resources In developing countries: implications for green recovery. Resour Policy 88:104338, https://www.sciencedirect.com/science/article/pii/S0301420723010498

Sun X (2022) Human capital, radical product innovation, and product proliferation: evidence from China. Emerg Mark Financ Trade 58(7):1938–1950. https://doi.org/10.1080/1540496X.2021.1945437

Tang W, Li G (2023) Enhancing competitiveness in cross-border e-commerce through knowledge-based consumer perception theory: an exploration of translation ability. J Knowl Econ https://doi.org/10.1007/s13132-023-01673-3

Teng Z, He Y, Wu R (2022) E-commerce: does sustainable logistics development matter? Sustainability 15(1):579, https://www.mdpi.com/2071-1050/15/1/579

Tolstoy D, Nordman ER, Hånell SM, Özbek N (2021) The development of international e-commerce in retail SMEs: an effectuation perspective. J World Bus 56(3):101165, https://www.sciencedirect.com/science/article/pii/S1090951620300936

Trapani L (2015) Testing for exogeneity in cointegrated panels. Oxf Bull Econ Stat 77(4):475–494. https://doi.org/10.1111/obes.12072

Villegas-Mateos A (2022) Toward a sustainable entrepreneurial ecosystem in Qatar. Sustainability 15(1):127, https://www.mdpi.com/2071-1050/15/1/127

Vukmirović V, Kostić-Stanković M, Pavlović D, Ateljević J, Bjelica D, Radonić M, Sekulić D (2021) Foreign direct investments' impact on economic growth in Serbia. J Balk East Stud 23(1):122–143. https://doi.org/10.1080/19448953.2020.1818028

Wagner M (2023) Fully modified least squares estimation and inference for systems of cointegrating polynomial regressions. Econ Lett 228:111186, https://www.sciencedirect.com/science/article/pii/S0165176523002112

Wang C, Liu T, Wen D, Li D, Vladislav G, Zhu Y (2021) The impact of international electronic commerce on export trade: evidence from China. J Theor Appl Electron Commer Res. 16(7):2579–2593. https://www.mdpi.com/0718-1876/16/7/142

Wang D, Zheng Y, Li G (2024) High-dimensional low-rank tensor autoregressive time series modeling. J Econ 238(1):105544, https://www.sciencedirect.com/science/article/pii/S0304407623002609

Wang J-F (2010) E-commerce communities as knowledge bases for firms. Electron Commer Res Appl 9(4):335–345. https://www.sciencedirect.com/science/article/pii/S1567422309000842

Wang Y, Zhao T (2015) Impacts of energy-related CO2 emissions: evidence from underdeveloped, developing and highly developed regions in China. Ecol Indic 50:186–195. https://www.sciencedirect.com/science/article/pii/S1470160X14005330

Wang Y, Gao H, Wang H (2024) The digital silk road and trade growth—a quasi-natural experiment based on silk road E-commerce. Res Int Bus Financ 67:102140, https://www.sciencedirect.com/science/article/pii/S0275531923002660

Wang Y, Jia F, Schoenherr T, Gong Y, Chen L (2020) Cross-border e-commerce firms as supply chain integrators: the management of three flows. Ind Mark Manag 89:72–88. https://www.sciencedirect.com/science/article/pii/S0019850118308642

Watson GF, Weaven S, Perkins H, Sardana D, Palmatier RW (2018) International market entry strategies: relational, digital, and hybrid approaches. J Int Mark 26(1):30–60. https://doi.org/10.1509/jim.17.0034

Wei L, Ullah S (2022) International tourism, digital infrastructure, and CO2 emissions: fresh evidence from panel quantile regression approach. Environ Sci Pollut Res 29(24):36273–36280. https://doi.org/10.1007/s11356-021-18138-2

Wei YD, Lin J, Zhang L (2020) E-commerce, Taobao Villages and regional development in China *. Geogr Rev 110(3):380–405. https://doi.org/10.1111/gere.12367

Winkler AM, Ridgway GR, Webster MA, Smith SM, Nichols TE (2014) Permutation inference for the general linear model. Neuroimage 92:381–397. https://www.sciencedirect.com/science/article/pii/S1053811914000913

Wooldridge JM (2010) Econometric analysis of cross section and panel data. MIT Press

Wright DK (2019) Long-term dynamics of pastoral ecology in northern Kenya: an old model for new resilience. J Anthropol Archaeol 55:101068, https://www.sciencedirect.com/science/article/pii/S0278416518302216

Xi X, Wei M, Teo BS-X (2023) The construction and evolution path of cross-border e-commerce ecosystem. Cent Eur Manag J 31(2):378–387. http://journals.kozminski.cem-j.org/index.php/pl_cemj/article/view/710

Xiao Y, Abula B (2023) Examining the impact of digital economy on agricultural trade efficiency in RCEP region: a perspective based on spatial spillover effects. J Knowl Econ https://doi.org/10.1007/s13132-023-01484-6

Yan Z, Lu X, Chen Y, Wang K (2023) Institutional distance, internationalization speed and cross-border e-commerce platform utilization. Manag Decis 61(1):176–200. https://www.emerald.com/insight/content/doi/10.1108/MD-09-2021-1172/full/html

Yang C (2012) Restructuring the export-oriented industrialization in the Pearl River Delta, China: institutional evolution and emerging tension. Appl Geogr 32(1):143–157. https://www.sciencedirect.com/science/article/pii/S0143622810001463

Yin ZH, Choi CH (2023) The effects of China's cross-border e-commerce on its exports: a comparative analysis of goods and services trade. Electron Commer Res 23(1):443–474. https://doi.org/10.1007/s10660-021-09483-y

Zhang C, Zeng W (2023) Evaluating the construction of a digital supervision platform for digital trade systems: a multilateral perspective. J Knowl Econ 十一月. https://doi.org/10.1007/s13132-023-01597-y

Zhang C-H, Zhang SS (2014) Confidence intervals for low dimensional parameters in high dimensional linear models. J R Stat Soc Ser B: Stat Methodol 76(1):217–242. https://academic.oup.com/jrsssb/article-abstract/76/1/217/7075942

Zhang M, Yang R (2022) FDI and spillovers: new evidence from Malaysia's manufacturing sector. Rev Dev Econ 26(2):847–877. https://doi.org/10.1111/rode.12857

Zhang Q, Sun Z, Wu F, Deng X (2016) Understanding rural restructuring in China: the impact of changes in labor and capital productivity on domestic agricultural production and trade. J Rural Stud 47:552–562. https://www.sciencedirect.com/science/article/pii/S0743016716300638

Zhang S, Chen C (2020) Does outward foreign direct investment facilitate China's export upgrading? China World Econ 28(5):64–89. https://doi.org/10.1111/cwe.12328

Zhang X (2019) Investigation of E-commerce in China in a geographical perspective. Growth Change 50(3):1062–1084. https://doi.org/10.1111/grow.12307

Zhao Y, He X, Ma L, Liu H (2022) Unbiasedness-constrained least squares state estimation for time-varying systems with missing measurements under round-robin protocol. Int J Syst Sci 53(9):1925–1941. https://doi.org/10.1080/00207721.2022.2031338

Zhong M, Wang Z, Ge X (2022) Does cross-border E-commerce promote economic growth? Empirical research on China's pilot zones. Sustainability 14(17):11032, https://www.mdpi.com/2071-1050/14/17/11032

Zhou X, Cai Z, Tan KH, Zhang L, Du J, Song M (2021) Technological innovation and structural change for economic development in China as an emerging market. Technol Forecast Soc Change 167:120671, https://www.sciencedirect.com/science/article/pii/S0040162521001037

Author contributions

The author confirms sole responsibility for the conception and design, analysis and interpretation, and manuscript preparation.

Competing interests

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

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