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Does the Exchange Rate-Trade Nexus Vary Across Manufacturing Industries?[1][2][3]

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Abstract: This study examines how bilateral trade responses of manufacturing industries to exchange rate (ER) movements differ across sectors and over time. To this end, we estimate the impact of both ER levels and uncertainty on manufacturing industry exports employing an industry level analysis. The gravity model estimation results indicate that real exchange rate (RER) depreciations increase total manufacturing exports. However, the direction and magnitude of these effects vary substantially across sectors and over time. The effects of RER depreciations become statistically insignificant or even reverse in technology-intensive sectors and in sectors with high foreign value-added content in exports. Our findings reveal that ER volatility negatively affects exports in most of the manufacturing industries. Sub-period analyses show that the results for the 1990-2005 period are consistent with conventional trade channel, whereas the ER-trade relationship weakens or reverses in many sectors during the 2006-2021 period.

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Araştırma Makalesi *Açık Erişim*

Döviz Kuru-Ticaret İlişkisi İmalat Sanayi Sektörleri Arasında Değişiyor mu?

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Anahtar Kelimeler: Döviz kuru, imalat sanayi ticareti, yerçekimi modeli
JEL Kodları: C33, F14, F31

Öz: Bu çalışma, imalat sanayi sektörel ihracatının döviz kuru hareketlerine karşı verdiği tepkilerin sektörler arasında ve zaman içinde nasıl farklılaştığını incelemektedir. Bu bağlamda çalışmada sektörel düzeyde veriler kullanılarak döviz kuru seviyeleri ve oynaklığındaki değişimlerin imalat sanayi ihracatı üzerindeki etkileri tahmin edilmiştir. Çekim modeli tahmin sonuçları, yerli paranın reel değer kayıplarının toplam imalat ihracatını artırdığını göstermektedir. Ancak bu etkilerin yönü ve büyüklüğü sektörler arasında ve zaman içinde değişmektedir. Reel döviz kuru değer kayıplarının etkileri, teknoloji yoğun ve ihracatta yüksek yabancı katma değer içeren sektörlerde istatiksel olarak anlamsız hale gelmekte veya tersine dönmektedir. Elde edilen buldular döviz kuru oynaklığının çoğu sektörde ihracatı olumsuz etkilediğini göstermiştir. Alt dönem analizleri, 1990-2005 dönemi bulgularının geleneksel ticaret kanalı ile uyumlu olduğunu, 2006-2021 döneminde ise döviz kuru-dış ticaret ilişkisinin zayıfladığını veya tersine döndüğünü göstermektedir.

1. Introduction

With the transition to floating ER regimes and the intensification of globalization, economies have become more sensitive and exposed to external shocks. In recent decades, ER movements have emerged as a major determinant of key macroeconomic variables-such as imports, exports, price levels, and output -through multiple transmission channels. As a central relative price in international economics, the effect of ER changes on foreign trade volumes continues to be a prominent topic in the literature.

In the conventional textbook models, a decline in the real value of the national currency is anticipated to positively affect trade balance through the price competitiveness effect. Numerous studies provide evidence supporting the positive impact of a competitive ER on foreign trade (Bahmani-Oskooee, 2001; Chaudhary et al., 2016; Goldstein & Khan, 1985). However, some studies such as Rose (1991), Hooper et al. (1998), Gagnon (2003), and Hatemi-J and Irandoust (2005) do not find any significant effect of the ER on foreign trade suggesting that the elasticities of exports and imports are low. On the other hand, the evolution of global production processes-spurred by growing globalization and technological progress-has made the ER-foreign trade relationship more complex. With the rise of global production networks, different stages of production have increasingly been carried out in different countries which significantly raised the import usage in production and exports. Consequently, a number of studies such as Jones and Kierzkowski (2001), Kharroubi (2011), Karadam and Özmen (2015), and Ahmed et al. (2017) has been suggested that trade effects of ERs may decrease as product become more complex and technologically intense.

The impact of ER volatility (ERVOL), as well as changes in its level, on international trade has attracted significant attention during the last decades. ERVOL is mostly discussed in the context of uncertainty costs (Clark, 1973) and risk management strategies in the literature (Klein, 1990). While ERVOL can negatively affect foreign trade by increasing uncertainty in planning and pricing processes, sectors that apply risk management through the use of financial instruments may become more resilient to these effects. On the other hand, moderate volatility can compel exporters to increase price flexibility, thereby enhancing long-term competitiveness (Auboin & Ruta, 2013). However, particularly in developing countries, excessive volatility increases vulnerability to external financing and supply chain shocks and may lead to structural problems which is referred to as "premature deindustrialization" in the literature (Rodrik, 2016). Even though numerous studies have investigated the impacts of ERVOL on foreign trade, employing different methods and datasets, there is no general consensus in this field. A significant portion of the literature presents evidence that ERVOL has a negative effect on foreign trade (Arize et al., 2000; Chowdhury, 1993; Fountas & Bredin, 1998; Pozo, 1992). However, some studies find no statistically significant effect (Aristotelous, 2001; Hooper & Kohlhagen, 1978); while others report a positive impact (Asseery & Peel, 1991; Doyle, 2001; Franke, 1991).

When analyzing the impact of ER fluctuations on international trade, it is essential to consider that these impacts may differ depending on the structural features of each sector. A number of theoretical and empirical studies reveal that the effect of ER changes on bilateral trade flows differs across sectors[4]. Such differences can arise from factors such as production structures, technological intensity, import usage, and the degree of integration into global value chains (Özmen, 2014). Theoretically, devaluation increases competitiveness

[4] See, Baldwin and Krugman, 1989; Sapir and Sekkat, 1995; Chen and Juvenal, 2018; Peridy, 2003; Thorbecke and Smith, 2010; Kharroubi, 2011; Torres et al., 2018; Neumann and Tabrizy, 2021, among others.

by lowering export prices, yet this effect is inversely related to a sector's dependency on imported intermediate goods (Campa & Goldberg, 1999). Peridy (2003) argues that sectoral variations in firms' risk management capacities, market structures, and production technologies lead to asymmetric responses to ER shocks. He particularly emphasizes the behavioral differences between technology-intensive sectors and traditional manufacturing industries. In labor-intensive sectors with low import content (e.g., textiles, food and beverages), currency depreciation raises export revenues, whereas in sectors with high import dependency (e.g., automotive, electronics), higher production costs may erode the price advantage provided by ER movements (Jones & Kierzkowski, 2001; Özmen, 2014: 4; Saygılı et al., 2010). While ER changes tend to have more pronounced effects on low value-added and price-sensitive products, brand value and quality advantages can partially offset these effects in technology-intensive industries. In terms of product characteristics, homogeneous goods generally exhibit higher price elasticity, whereas higher-skill and higher quality products tend to be less responsive to ER fluctuations due to lower elasticity, higher profit margins, and broader market reach (Berman et al., 2012; Caglayan & Demir, 2019).

On the other hand, ERVOL complicates investment and sourcing decisions of sectors through uncertainty and risk premiums (Bodnar & Gentry, 1993). Small firms tend to be more vulnerable to currency fluctuations due to their lower usage of financial hedging instruments, which can disrupt cash flows and negatively affect export performance (Byrne et al., 2008; Taggart, 1999). However, firms with flexible production structures and strong financial risk management capabilities may turn ERVOL into an opportunity through pricing strategies or geographical diversification (De Grauwe, 1988; Dellas & Zilberfarb, 1993). Therefore, the net effect of RER movements varies depending on multiple factors, including the sector's production structure, product diversity, flexibility capacity, level of imported input usage, degree of integration into global value chains, and financial resilience (Frenkel, 2004; Soto, 2008).

Building on these considerations, this study investigates how changes in both ER levels and ERVOL affect foreign trade across manufacturing subsectors. The empirical analysis relies on a panel dataset covering 55 countries, which together account for approximately 82% of global exports over the period 1990-2021. The focus is on 20 manufacturing subsectors classified at the ISIC Rev. 4. Using gravity models, export equations are estimated separately for total manufacturing and for each sub-sector over the full sample period (1990-2021), as well as for two sub-periods (1990-2005 and 2006-2021), in order to evaluate how sectoral trade responses to ER movements and uncertainty have evolved over time.

This study aims at contributing to the existing empirical literature in a number of ways: First, the paper examines the effects of ER fluctuations on manufacturing exports in an industry-by-industry basis. Although previous research has analyzed the ER-trade nexus using firm-level or sectoral data, relatively few studies estimate ER sensitivity of trade separately for individual industries. Most of the analyses of the previous literature using sectoral data relies on pooled data or sectoral groupings[5]. There exist only a few studies which estimate sector-specific responses of trade to exchange rates. These studies, however, either employs only one country's or a few advanced country's data. The dataset of this study, instead, cover a broad heterogeneous set of countries including both developed and developing economies. Secondly, previous studies focus either on the effects of ER appreciations and depreciations or exclusively on ERVOL[6]. In contrast, this study jointly analyzes the effect of ER levels and ERVOL on exports at the industry level.

[5] See Colacelli (2008), Tarakçı et al. (2022), Bilgin and Berber (2023), and Palazzo (2024).
[6] See Peridy (2003), Oguro et al. (2008), Simakova (2018), and Thorbecke and Salike (2020).

Thirdly, apart from the previous studies, this paper examines how sectoral trade responses to ER movements and uncertainty have evolved over time by estimating the export equation for different sub-periods. Therefore, this study seeks to fill the gap in the literature by analyzing the effects of the changes in RER levels and ERVOL for individual manufacturing sectors employing a broad panel dataset covering both advanced and developing countries and exploring whether there exist periodical differences in the ER-trade nexus.

The industry- and period-specific findings indicate substantial heterogeneity in the impact of ER movements across sectors and over time. During 1990-2005, currency depreciation generally promotes exports in nearly all manufacturing subsectors. However, in the 2006-2021 period, these effects largely become statistically insignificant or even reverse in most industries, with the exception of traditional labor-intensive sectors such as apparel and wood and cork products. The change is particularly marked in high-technology industries, including computer, electronic and optical products. In addition, while ERVOL exerts only a limited effect on sectoral trade during the 1990s, its negative impact on exports becomes more pronounced from the 2000s onward. The overall results imply that manufacturing restructuring, characterized by intensified use of imported intermediates and deeper global value chain integration, has significantly influenced how trade flows respond to ER movements, with notable cross-industry heterogeneity.

The paper is structured as follows: Section 2 informs about the data set and provides some stylized facts on the structure of world manufacturing industrial trade. Models and variables are introduced in section 3. Section 4 presents the findings. Section 5 concludes by summarizing the key findings and highlighting the study's contributions and policy implications.

2. The Dataset and Some Stylized Facts on the Sectoral World Trade

Since the early 21st century, there has been a profound structural transformation in global production processes due to factors such as globalization, the liberalization of trade and financial flows, advances in information technologies, and the expansion of global value chains (GVCs). Worldwide manufacturing production has been shaped by multiple developments, including the spread of just-in-time production systems led by Asia (Ohno, 1989; Womack et al., 1990), the adoption of nearshoring strategies by countries neighboring the United States (McKinsey Global Institute, 2020), the restructuring of supply chains (World Bank, 2020), advancements in digitalization and automation technologies with the Industry 4.0 revolution (Kagermann et al., 2013), and reshoring trends shifting production back to home countries (BCG, 2022). The manufacturing industry is a critical sector at the center of global trade, and, particularly with the expansion of GVCs it has increased the international interdependence of production processes. Therefore, this study focuses on manufacturing subsectors in order to examine the sectoral impacts of ER changes.

The dataset covers annual sectoral trade data of 55 countries for the 1990-2021 period[7]. These countries account for 82% of world manufacturing exports over the analysis period. The list of countries included in the dataset is presented in Table 1. The empirical analysis covers 20 manufacturing subsectors classified at the two-digit level ISIC Rev.4. These subsectors and their corresponding technological-intensity classifications are presented in Table 2. The study employs an unbalanced panel dataset with a time

[7] The dataset encompasses trade flows between 55 economies and their 54 trading partners -which are selected according to the adequacy of data for model estimation.

dimension of T=32 and a cross-sectional dimension of N=2,970 (55×54). Export equations are estimated for total manufacturing as well as separately for each industry.

Table 1. The list of countries

Argentina, Estonia, Malaysia, Slovakia, Australia, Finland, Mexico, Slovenia, Austria, France, Morocco, South Africa, Belgium, Germany, Netherlands, Spain, Brazil, Greece, New Zealand, Sweden, Bulgaria, Hungary, Norway, Switzerland, Canada, India, Pakistan, Thailand, Chile, Indonesia, Peru, Tunisia, China, Ireland, Philippines, Turkiye, Colombia, Israel, Poland, Ukraine, Croatia, Italy, Portugal, United Kingdom, Czechia, Japan, Romania, United States, Denmark, Korea, Russia, Vietnam, Egypt, Luxembourg, Singapore

Source: Prepared by the authors.

Table 2. The List of Manufacturing Sub-sectors

ISIC Code-Industry
Low Tech.
I10-12-Food pr., beverages and tobacco
I13-Textiles
I14-Wearing apparel
I15-Leather and rel. pr.
I16-Wood pr. and cork
I17-Paper and paper pr.
Medium-Low Tech.
I19-Coke and refined petroleum pr.
I22-Rubber and plastics pr.
I23-Other non-metallic mineral pr.
I2410-Iron and steel
I2420-Non-ferrous metals
I25-Fabricated metal pr., except machinery and equipment
Medium-High Tech.
I20-Chemicals and chemical pr.
I27-Electrical eq.
I28-Machinery and eq. n.e.c.
I29-Motor vehicles, trailers and semi-trailers
I30-Other transport eq.
I3250-Medical and dental instruments and supplies
High Tech.
I21-Basic pharmaceutical pr.
I26-Computer, electronic and optical pr.

Source: Prepared by the authors.
Note: Categorized based on the OECD technology intensity classification.

In order to help understanding and interpreting the estimation results, we first provide some stylized facts on the structure of our dataset. To capture period-specific dynamics and examine the structural transformations in sectoral foreign trade patterns the analysis divides the sample into two sub-periods as 1990-2005 and 2006-2021. In order to present the sectoral composition of world trade within the scope of our dataset, Figure 1 presents the export shares of manufacturing subsectors for 55 countries by dividing the period into two sub-periods: 1990-2005 and 2006-2021. According to the figure, I10-12, I2410, I29 and I20 are the sectors with the highest export shares. By contrast, a comparatively limited export presence is observed in I3250 and I21. During the 2006-2021 period, export shares increase across most industries, with the exception of sectors I10-12, I13-I15, I16, I17, I2410 and I2420. Particularly strong growth in export shares is observed in sectors I26, I27, I28 and I21. Overall, the figures indicate that there has been an increase in export of high-technology sectors since the 2000s.

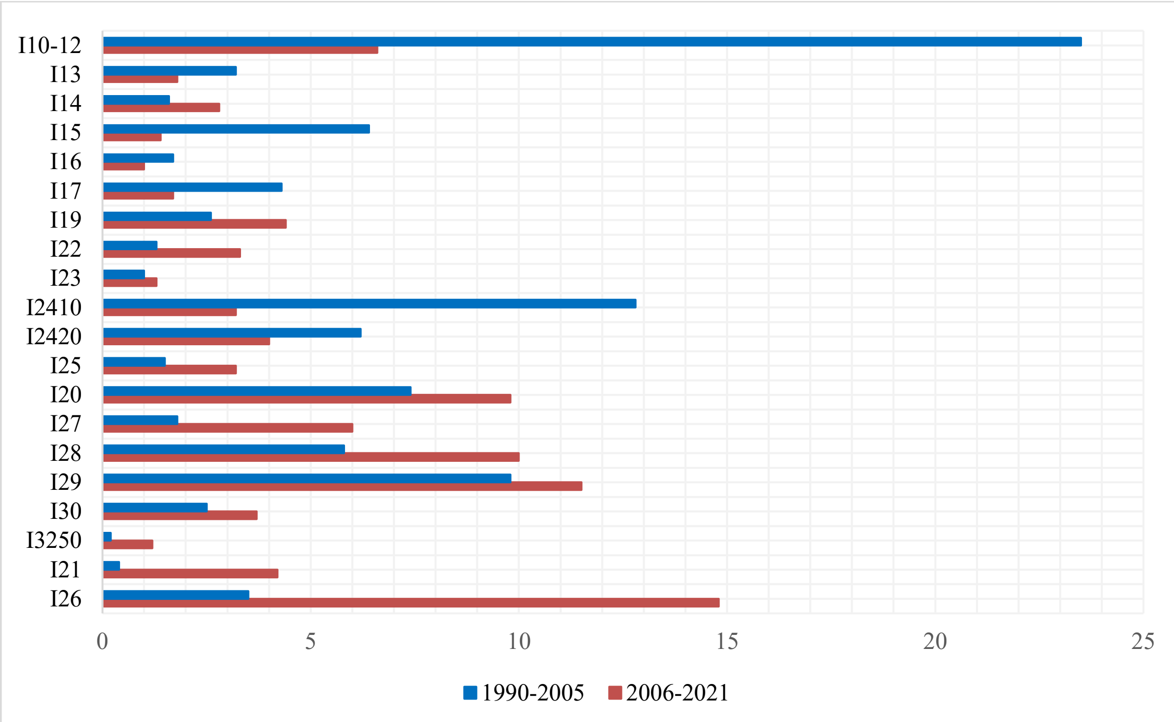

Figure 1. Shares of Manufacturing Sub-sectors in the Total Manufacturing Exports (1990-2005 and 2006-2021)
Source: Prepared by the authors using data from the OECD STAN database.

Figure 2 presents a comparative representation of the export shares of manufacturing sub-sectors classified according to the OECD's technological intensity classification. During 1990-2005, low-technology products accounted for the largest share of exports, whereas this leading position shifted to medium-high-technology products in 2006-2021 period. While the high-technology group had the smallest share (less than 5%) before 2006, its share rose sharply after 2005, reaching around 15% in manufacturing exports.

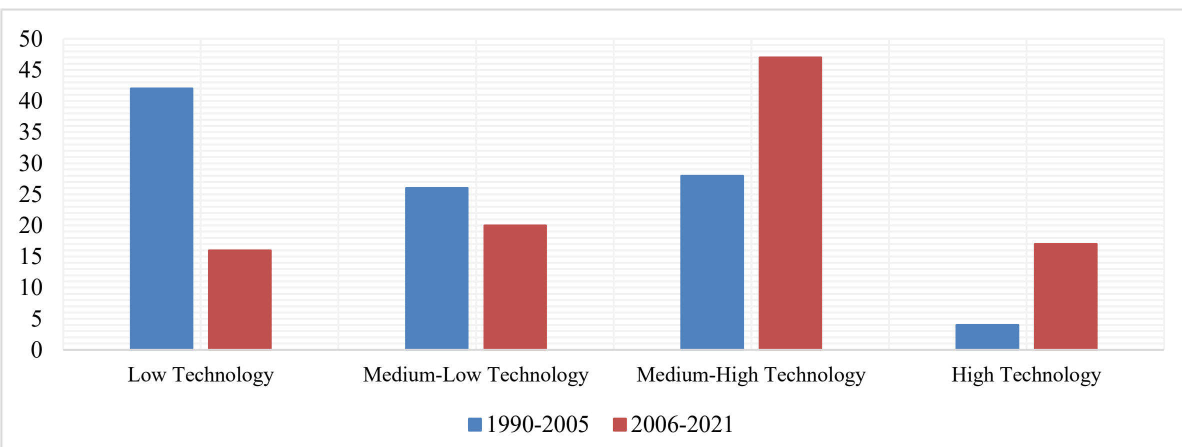

Figure 2. Export Shares of the Manufacturing Sectors by Technology Intensity (1990-2005 and 2006-2021)
Source: Prepared by the authors using OECD STAN database data.

As denoted in earlier sections, the degree of vertical specialization or integration into GVCs can change the ER responsiveness of sectoral exports and imports (Ahmed et al., 2017; Arndt & Huemer, 2005; Jones & Kierzkowski, 2001; Karadam & Özmen, 2015; Kharroubi, 2011) The share of foreign value added (FVA) in exports is used as an indicator of the backward linkages (i.e. use of imported inputs) of the industries

(Cigna et al., 2022; Guilhoto et al., 2019). In this context, Figure 3 presents the FVA shares in exports for 55 countries across 17 sectors over the period 1995-2006 and 2007-2019. The figure indicates that FVA content is most prominently concentrated in sectors I19, I26 and I29. This indicates that these sectors are highly integrated into global production networks and have intensive use of imported inputs in both production and exports. In contrast, a comparatively limited FVA contribution is observed in sector I16 as well as in I13-I15. This suggests that these industries use mostly domestic raw materials, follow labor-intensive production structures, and are less integrated into GVCs. The figure shows that FVA shares increased in nearly all sectors during the latter period. A marked upward trend is evident in I29, I30, I21, I31-I32 and I10-I12. In contrast, more limited growth is observed in I23, I16 and I24. These figures indicate that the import dependence of the manufacturing sector has risen significantly during 2007-2019, with the degree of dependence varying across sectors.

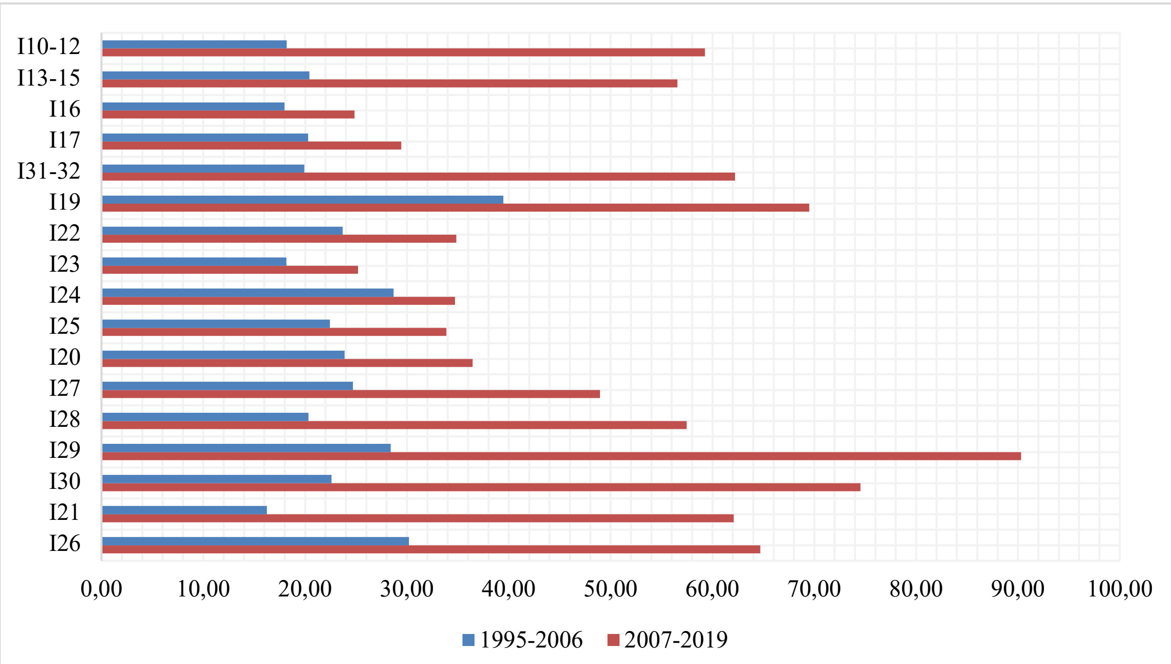

Figure 3. Foreign Value-Added Shares in Exports (1995-2006 and 2007-2019)
Source: Created by the authors using OECD TIVA database data.

Due to the technological advances and the decrease in trade barriers, participation into GVCs has risen in recent years (Amador & Cabral, 2016). This process has encouraged a stronger dependence on imported intermediate goods, suggesting that engagement in GVCs significantly influences the connection between exchange rates and export outcomes (Ollivaud et al., 2015). A body of empirical evidence (e.g., Ahmed et al., 2017; Amiti et al., 2014; Boz et al., 2015; Patel et al., 2019) demonstrates that GVCs significantly reduce ER elasticities of trade.

3. The Model and Method

The study examines the effect of bilateral RER levels and ERVOL on sectoral exports using bilateral trade data for 20 manufacturing subsectors of 55 countries over the period 1990-2021. Empirical analysis is conducted adopting an augmented gravity model framework.

The gravity model is based on the Universal Law of Gravitation formulated by Isaac Newton in the field of physics. According to this law, the gravitational force between two bodies is directly proportional to their respective masses and inversely proportional to the square of the distance between them. The seminal contributions of Tinbergen (1962), Pöyhönen (1963), and Linnemann (1966) represent the earliest attempts to formally specify the gravity model and employ it in empirical analyses of international trade flows. In particular, Tinbergen (1962) provides evidence that bilateral trade flows are positively associated with the economic size of countries while being inversely related to the geographical distance between them. The gravity model of international trade, as adapted by Tinbergen (1962), can be expressed as follows:

$$\mathrm{T_{ab}} = \mathrm{G}\frac{\mathrm{Y_a Y_b}}{\mathrm{D_{ab}}} \tag{1}$$

In the equation, T_{ab} denotes the bilateral trade flow between countries a and b. G represents the gravitational constant, while Y_a and Y_b denote the economic sizes of countries a and b, respectively, as measured by GDP. D_{ab} refers to the geographical distance between the two countries.

The gravity model has been extended and refined along multiple dimensions by a substantial body of literature[8]. According to the Structural Gravity Model, one of the most influential recent contributions, proposed by Anderson and Van Wincoop (2003), trade flows are determined by economic size, trade costs, and "multilateral resistance," as follows:

$$X_{ab} = \frac{Y_a Y_b}{Y}\left(\frac{t_{ab}}{\mathrm{P}_a \mathrm{P}_b}\right)^{1-\sigma} \tag{2}$$

According to Eq. (2), the volume of trade from country a to country b (X_{ab}) depends on the economic sizes of the two countries Y_a a and Y_b, the trade costs between them (t_{ab}) and their respective trade relationships with other partners. As emphasized by Anderson and Van Wincoop (2003), a country's trade costs are not determined solely by bilateral costs between two countries, but also by the structure of its trade costs with all other trading partners. This interdependence is captured by the concept of "multilateral resistance". Multilateral resistance is decomposed into inward resistance P_a and outward resistance (P_b), and is defined as presented in Eq. (3):

$$\mathrm{P}_a^{1-\sigma} = \sum_{b=1}^{N}\left(\frac{t_{ab}}{P_b}\right)^{1-\sigma} Y_b \quad \text{and} \quad \mathrm{P}_b^{1-\sigma} = \sum_{a=1}^{N}\left(\frac{t_{ab}}{\mathrm{P}_a}\right)^{1-\sigma} Y_a \tag{3}$$

In the study, the gravity model described above, is augmented with the RER and its volatility in order to analyze the impact of ER level changes and uncertainty on sectoral trade. As emphasized by Bergstrand (1985), the bilateral RER constitutes a key macroeconomic indicator that influences trade volumes through its effects on relative prices and trade costs. Furthermore, RER volatility (VOL) is incorporated into the model to capture the risk-enhancing effects of uncertainty on trade, as demonstrated by Arize (1998), and Bahmani-Oskooee and Hegerty (2007). A number of additional variables or dummies are also incorporated into the model to represent the effects of other factors on international trade, such as common border, trade agreements and common language as suggested by a number of studies such as Bergstrand (1985) and Deardoff (1995).

[8] See Aitken (1973), Anderson (1979), Bergstrand (1985), Helpman and Krugman (1985), Mccallum (1995), Deardroff (1998), and Anderson and Van Wincoop (2003).

The estimated log-linearized form of gravity export model is presented in Eq. (4) as:

$$\mathrm{lnEXP_{ab,t}} = \beta_0 + \beta_1 \mathrm{lnGDP_{a,t}} + \beta_2 \mathrm{lnGDP_{b,t}} + \beta_3 \mathrm{lnRER_{ab,t}} + \beta_4 \mathrm{lnVOL_{ab,t}} + \beta_5 \mathrm{lnDIST_{ab,t}} + \beta_6 \mathrm{Contig_{ab,t}} + \beta_7 \mathrm{TA} + \beta_8 \mathrm{Comcur} + \beta_9 \mathrm{Colony} + \beta_{10} \mathrm{Comlang_{ab,t}} + \delta_{ab} + \gamma_t + \epsilon_{ab,t} \quad (4)$$

In the model, the dependent variable is bilateral total manufacturing and sectoral real exports. Nominal export values are from the OECD-STAN database and deflated by the countries' CPI values to obtain real figures. GDP_a (GDP_b) denotes the real GDP of the domestic country (trading partner) and represents the economic size of these countries. GDP also reflects the export supply capacity of the exporting country and the import demand of the importing country. National income data are from the World Bank's WDI database.

The bilateral RER, one of the key explanatory variables in the analysis, is calculated as follows:

$$\mathrm{RER} = \mathrm{NER} * \frac{\mathrm{P_a}}{\mathrm{P_b}} = \frac{\mathrm{EXC_b}}{\mathrm{EXC_a}} * \frac{\mathrm{P_a}}{\mathrm{P_b}} \quad (5)$$

In Eq. (4), the bilateral RER is calculated using nominal ER and CPI data which are from the Bank for International Settlements (BIS) and the International Financial Statistics (IFS) database, respectively. In the equation, EXC_b the trading partner's ER against the U.S. dollar, EXC_a the domestic country's ER against the U.S. dollar, P_b the trading partner's CPI, and P_a the domestic country's CPI. By definition, an increase in RER implies a real appreciation of the domestic currency.

Bilateral RER volatility (VOL) is included in the export equations to capture the effects of ER uncertainty on trade, following Arize (1998), and Bahmani-Oskooee and Hegerty (2007). VOL is computed using monthly bilateral RER data and the moving average standard deviation (MASD) method (Equation 3). This approach has been widely applied in the literature, including studies such as Köse et al. (2008), Kaya and Çömlekçi (2013), Kasman (2003), Chowdhury (1993), Serenis and Tsounis (2014), Thuy and Thuy (2019), Aslan and Parmaksız (2025), and Tarasenko (2021). The MASD formula is as follows:

$$V = \sqrt{\frac{1}{n} * \left(\sum_{i=1}^{n} (x_{t+i-1} - x_{t+i-2})^2\right)} \quad (6)$$

As one of the standard variables of the gravity model, Distance (DIST), is measured in kilometers as a proxy for transportation costs and obtained from the CEPII database. In terms of dummy variables, border sharing (Contig), trade agreements (TA), common currency (Comcur), and common language (Comlang) dummies are incorporated into the model. The model also consists pairwise dummy variables (δ_{ab}) and time effects (γ_t), as recommended by numerous studies. Pairwise fixed effects capture multilateral resistance and time-invariant ties between countries. In the gravity model, country-pair (pairwise) dummy variables have shown to be highly effective in addressing the multilateral trade resistance (Baldwin & Taglioni, 2006; Feenstra, 2006; Hummels & Schaur, 2013). Time effects are included to control for general time-varying factors such as global economic crises, changes in trade policies, or fluctuations in energy prices. The definitions and sources of the variables included in the models are presented in Table A.1 in Appendix.

All variables apart from the dummy variables are specified in natural log form. As common in the literature (Baier & Bergstrand, 2007; Chit et al., 2010; Egger, 2000; Frede & Yetkiner, 2017; Micco et al., 2003), the export gravity equation presented above in Eq. (4) is estimated using the fixed effects method [9] [10]. The fixed effects estimator offers significant advantages as suggested by Dell'Arricia (1999), Hummels and Schaur (2013), Feenstra (2006), Egger and Pfaffermayr (2003), Baier and Bergstrand (2009), and Baldwin and Taglioni (2006). In particular, by allowing for the joint inclusion of both country-pair fixed effects and time fixed effects, it facilitates the proper accounting of multilateral trade resistance, controls for common shocks and unobserved pair-specific factors and helps mitigate omitted variable bias. Baldwin and Taglioni (2006) argue that neglecting multilateral trade resistance leads to biases arising from omitted or mis-specified variables, the so-called "gold medal mistake." They demonstrate that incorporating country-pair dummy variables substantially mitigates this bias and outperforms the use of simple country dummies. Accordingly, the inclusion of country-pair fixed effects has become one of the most widely adopted approaches in the empirical gravity literature to account for multilateral resistance. On the other hand, Dell'Arricia (1999) shows that fixed effects enhance the theoretical consistency of the model by absorbing unobserved heterogeneity specific to country pairs. In addition, failure to control for global shocks-such as financial crises, policy changes, or fluctuations in energy prices-may give rise to the "bronze mistake" (Baldwin & Taglioni, 2006). This issue can be addressed through the inclusion of time effects in the fixed effects methodology. Moreover, by controlling for unobserved heterogeneity, it reduces omitted variable bias and enhances the reliability of estimated results, as also highlighted by Bacchetta et al. (2012). Overall, the fixed effects estimator constitutes an essential tool in gravity models, not only for ensuring theoretical and empirical consistency but also for addressing endogeneity concerns (Baier & Bergstrand, 2009).

In all specifications, standard errors are adjusted to account for heteroscedasticity. The export model is first estimated for the total manufacturing industry and then separately for 20 sub-sectors. Subsequently, the sectors were classified into four categories according to their technology intensity (see Table 2). The models are then estimated for these four groups. Such sectoral and bilateral analysis dissipate the potential endogeneity problems since it is unlikely that omitted variables can affect both sectoral bilateral trade and overall bilateral RER (Colacelli, 2008; Peridy, 2003).

4. Empirical Results

4.1. Findings on Total Manufacturing Industry

In this section, we first estimate the impact of the ER and ERVOL on the total manufacturing industry's exports for the whole period 1990-2021, as well as for two sub-periods: 1990-2005 and 2006-2021. The parameter estimates of the export model for the full period are presented in the first column of Table 3.

[9] We initially estimate the models employing the fixed effects and random effects estimation methods. Since the Hausman test indicated that the fixed effects estimator is consistent, the study reports the fixed effects estimation results. The Hausman test results are available upon request.

[10] Silva and Tenreyro (2006) suggest the use of Poisson Pseudo-maximum-likelihood (PPML) Method which estimates the gravity model in multiplicative form if the zero trade values are common in the dataset and in the presence of heteroscedasticity. In our dataset, we select the countries with the largest volume of trade with each other and that have sufficient observations to estimate the export gravity model. Therefore, zero trade values are not common in our dataset. The standard errors are also adjusted to account for heteroscedasticity in all specifications. As stressed by Martinez-Zarzoso (2013) and Shahriar et al. (2019), each method to estimate gravity models (e.g. fixed effects, Tobit models, FGLS, PPML, …) has their own advantages and disadvantages and the choice of the estimator has to be made for each specific dataset. Accordingly, as the most common estimator for gravity equations, we prefer to employ fixed effects estimator instead of PPML given its advantages as described in the text.

Table 3. Estimation Results of the Gravity model for Total Manufacturing Exports

Variables	Full Period (1990-2021)	1990-2005	2006-2021
GDPa	0.728*** (0.06)	2.191*** (0.14)	0.392*** (0.07)
GDPb	0.992*** (0.07)	1.100*** (0.17)	1.095*** (0.07)
RER	-0.153*** (0.05)	-0.705*** (0.06)	0.506*** (0.05)
VOL	-0.086*** (0.01)	0.014 (0.02)	-0.170*** (0.01)
DIST	-1.311*** (0.09)	-2.696*** (0.19)	-1.394*** (0.10)
Contig	1.184*** (0.15)	1.191*** (0.26)	0.186 (0.16)
TA	0.150*** (0.03)	0.053 (0.05)	0.045* (0.03)
Comcur	1.610*** (0.16)	-1.070*** (0.32)	1.395*** (0.18)
Colony	0.774*** (0.2)	1.926*** (0.38)	-0.491** (0.21)
Comlang	1.319*** (0.1)	-0.232 (0.16)	1.494*** (0.12)
N	84704	38073	46631
R^2	0.902	0.907	0.96
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Source: Prepared by the authors.
Note: Robust standard errors in parentheses. ***, **, and * indicate 1%, 5% and 10% level of significance, respectively.

The findings indicate that the RER negatively and significantly affects total manufacturing exports, implying that currency depreciation stimulates exports and supports the trade balance. This result aligns with previous empirical evidence. (e.g., Bahmani-Oskooee & Hegerty, 2007; Choudhri & Hakura, 2006; Rose & Yellen, 1989).

VOL, as a measure of ER uncertainty, has a negative and statistically significant effect on manufacturing exports, indicating that higher volatility reduces export volumes. This result supports the arguments of the studies suggesting that greater variability in ERs undermines economic stability, thereby increasing uncertainty and risk levels in foreign trade. This, in turn, triggers exporters' risk aversion behavior, leading them to focus on domestic rather than foreign markets. The findings of studies such as Kenen and Rodrik (1986), Pozo (1992), Chowdhury (1993), Arize (1998), and Acaravcı and Dağlı (2021) also support the adverse effects of ERVOL on trade.

According to the estimation results, the GDPs of the exporting and importing countries (GDPa and GDPb) have significantly positive while DIST has a significantly negative effect on a manufacturing industry exports as expected. The coefficients of the dummy variables -Contig, TA, Comlang, Comcur, and Colony- are positive consistently with expectations.

The sample period covers profound economic and structural changes in global production and trade. Since the 2000s, intensified globalization, technological progress, trade liberalization, and rising capital flows have reshaped manufacturing dynamics. Declining trade barriers and transport costs have fostered complex global production networks, increasing cross-country interdependence through the expansion of global value chains (Guilhoto et al., 2019). As emphasized in the literature (e.g., Ahmed et al., 2017; Arndt & Huemer, 2007; Jones & Kierzkowski, 2001; Kharroubi, 2011; Neumann & Tabrizy, 2021), these structural transformations are likely to influence the ER sensitivity of trade. Accordingly, to examine whether the effect of ER changes has shifted over time, the sample is split into two as 1990-2005 and 2006-2021. The estimation results for total manufacturing exports are reported in columns 3-6 of Table 3.

During 1990-2005, the RER coefficient is significantly negative, indicating that a real depreciation stimulates exports in line with the traditional Mundell-Fleming framework. In contrast, in 2006-2021, the coefficient turns positive, suggesting a reversal of this effect. While VOL is not statistically significant in the first period, it becomes negative and significant in the latter, implying that ER uncertainty increasingly dampens manufacturing exports. Overall, the findings show sensitivity of exports to ER levels and volatility differ markedly across periods. The growing integration of manufacturing into global value chains-accompanied by higher import content in production-appears to have reduced the gains from currency depreciation, limiting its positive impact on exports. In the same vein, the negative consequences of a home currency appreciation may be limited, as cheaper imported inputs can mitigate some of the export-related losses (Neumann & Tabrizy, 2021). Campa and Goldberg (1995) highlight that producers with greater exposure to imported inputs experience a larger decline in profitability following a domestic currency depreciation. In line with these arguments, contrary to the earlier period, our results indicate that manufacturing exports benefit from the real appreciation of the domestic currency in the 2006-2021 period. These findings are consistent with the suggestions of studies such as Jones and Kierzkowski (2001), Arndt and Huemer (2005), Kharroubi (2011), Ahmed et al. (2015), and Neumann and Tabrizy (2021). On the other hand, as opposed to the earlier period, widespread adaption of flexible exchange rate regimes, higher synchronization of production due to deeper GVC integration and increased financial volatility can make exchange rate volatility a systematic barrier to trade, leading to a clearer negative impact on exports in the latter period.

Period-specific estimation results also reveal notable changes in other gravity variables. Considerable negative effects of DIST on both manufacturing exports in the 1990-2005 period seem to decline significantly in the subsequent period. This is largely associated with the reduction in transportation costs resulting from advancements in container shipping, the implementation of logistics optimization practices, the expansion of air cargo capacity, and the spread of digital trade. This finding is also consistent with the results for some other dummy variables. During the 1990s, sharing a land border provided a significant cost advantage for the countries, and trade agreements, tariff reductions, and customs facilitation measures created much more pronounced trade-enhancing effects. In contrast, after the 2000s, the increased liberalization of global trade may have reduced the marginal effect of trade agreements. Similarly, while colonial history and historical ties exerted a strong influence on trade in the 1990-2005 period, advances in globalization and digital communication after the 2000s may have diminished the importance of these factors. On the other hand, in the 1990-2005 period, the common language factor may have been overshadowed by traditional trade barriers, such as distance. However, in the post 2006 period, as trade has become more complex, knowledge-intensive, and digital in nature, the communication ease and trust provided by a common language can be regarded as one of the major facilitating forces in international trade.

4.2. Industry-Level Analysis

Most existing studies rely on aggregate country-level data to evaluate the effects of ER levels and VOL on trade, paying limited attention to sectoral heterogeneity. Research using firm- or industry-level data generally adopts pooled estimations (e.g., Caglayan & Di, 2010; Caglayan et al., 2013; Colecelli, 2008; Wierts et al., 2012). Only a few studies-such as Peridy (2003), Fawcett (2010), and Thorbecke and Salike (2020)-provide sectoral disaggregation, and these typically focus either on ER levels or volatility, often for a small group of advanced economies. Tables 4 and 5 report industry-specific export estimates for manufacturing subsectors, including results by technological intensity.

Table 4 reveals strong heterogeneity in sectoral export responses to RER changes. A real depreciation significantly increases exports in 9 of 20 sectors (I14, I16, I23, I2410, I2420, I20, I28, I29 and I30) particularly which are low- and medium-low-technology industries with relatively low imported input shares. In these sectors, production relies more heavily on domestic inputs and goods are relatively homogeneous, making demand highly price-sensitive; thus, depreciations enhance price competitiveness and lead to higher export volumes (Campa & Goldberg, 1995). This result aligns with findings by Caglayan and Demir (2019), Palazzo (2024), and Goda et al. (2024), which find that real depreciation stimulates exports especially in low- and medium-skill, labor-intensive industries. On the other hand, the effect of RER changes on exports is statistically insignificant in 8 sectors (I10-12, I13, I17, I19, I22, I25, I27, I21 and I2420). Four of these sectors (I19, I27, I25 and I22) are among those with a high share of FVA in exports, as shown in Figure 3. As demonstrated by Arndt and Huemer (2007) and Freund et al. (2011), in sectors with a high share of imported inputs in exports (i.e., sectors characterized by a high degree of vertical specialization), the effect of ER changes on exports can be neutralized. As exported goods increasingly embody imported intermediate inputs, depreciations raise production costs, thereby offsetting gains in price competitiveness and obscuring the net export response. Firm-level evidence further supports this mechanism, showing that exporters with high import intensity exhibit significantly lower exchange rate pass-through into export prices, as exchange rate changes simultaneously affect both marginal costs and markups (Amiti et al., 2014). Finally, the coefficient of the RER is significantly positive for 3 sectors (I15, I26 and I3250) implying a depreciation of domestic currency deters exports for these industries. It is noteworthy that this negative effect is observed particularly in medium-high and high-technology-intensive sectors. These findings indicate that for these industries, such as I3250 and I26, an appreciation of the national currency reduces the cost of imported inputs, thereby increasing production and exports, a result which is also shown by Goda et al. (2024) and Sierra and Manrique (2014). Moreover, high-technology goods are typically differentiated and compete on quality and innovation rather than price, leading to lower demand elasticity and widespread pricing-to-market behavior (Krugman, 1987). The prevalence of dominant currency pricing further limits exchange rate pass-through to export prices, weakening the traditional competitiveness channel (Gopinath et al., 2020). In addition, high-technology exports depend largely on structural factors such as R&D intensity and human capital, which are not directly responsive to

Table 4. Estimation Results of the Gravity Model for Export (1990-2021)

	GDPa	GDPb	RER	VOL	DIST	Contig	TA	Comcur	Colony	Comlang	N	R^2
Low-Technology	0.139** (0.07)	1.375*** (0.07)	-0.072 (0.05)	-0.091*** (0.01)	-0.928*** (0.09)	0.527*** (0.15)	0.155*** (0.04)	2.920*** (0.17)	0.418** (0.2)	1.734*** (0.1)	82736	0.89
I10-12	-0.01 (0.08)	1.363*** (0.08)	-0.077 (0.06)	-0.063*** (0.02)	-1.086*** (0.1)	-0.611*** (0.18)	0.094** (0.04)	3.171*** (0.19)	1.311*** (0.23)	1.173*** (0.12)	79694	0.85
I13	0.373*** (0.09)	1.013*** (0.1)	-0.089 (0.07)	-0.102*** (0.02)	-1.170*** (0.13)	1.060*** (0.22)	0.155*** (0.05)	3.804*** (0.23)	1.855*** (0.27)	2.906*** (0.14)	76272	0.83
I14	-0.318*** (0.11)	2.047*** (0.11)	-0.193** (0.08)	-0.171*** (0.02)	-0.824*** (0.14)	1.920*** (0.19)	0.116** (0.06)	7.052*** (0.23)	-2.133*** (0.31)	3.595*** (0.11)	71380	0.85
I15	-0.002 (0.1)	1.489*** (0.11)	0.170** (0.08)	-0.178*** (0.02)	-0.175 (0.13)	2.294*** (0.19)	0.066 (0.06)	4.030*** (0.22)	-2.016*** (0.31)	3.865*** (0.11)	68471	0.82
I16	-0.065 (0.12)	1.799*** (0.12)	-0.226*** (0.08)	-0.125*** (0.02)	-3.076*** (0.15)	-0.987*** (0.24)	0.016 (0.06)	1.627*** (0.28)	-1.710*** (0.32)	0.263* (0.16)	66982	0.82
I17	1.133*** (0.11)	0.934*** (0.11)	0.09 (0.09)	-0.091*** (0.02)	-1.457*** (0.15)	2.686*** (0.25)	0.126** (0.06)	2.013*** (0.26)	2.056*** (0.33)	1.956*** (0.17)	69964	0.81
Medium-Low Technology	0.756*** (0.08)	0.819*** (0.09)	-0.155** (0.07)	-0.118*** (0.02)	-2.166*** (0.11)	0.934*** (0.19)	0.155*** (0.04)	0.038 (0.21)	0.687*** (0.26)	-0.092 (0.13)	82186	0.9
I19	0.101 (0.17)	1.287*** (0.17)	-0.101 (0.12)	-0.041 (0.03)	-0.501** (0.22)	5.454*** (0.36)	0.197** (0.1)	5.984*** (0.43)	-2.165*** (0.45)	4.849*** (0.24)	47927	0.72
I22	0.629*** (0.08)	1.048*** (0.09)	0.042 (0.06)	-0.116*** (0.01)	-0.742*** (0.11)	2.326*** (0.18)	0.127*** (0.04)	3.237*** (0.19)	1.827*** (0.24)	3.819*** (0.12)	79898	0.85
I23	0.502*** (0.09)	1.129*** (0.1)	-0.367*** (0.07)	-0.060*** (0.02)	-1.439*** (0.13)	2.122*** (0.21)	0.112** (0.05)	2.824*** (0.23)	0.794*** (0.28)	1.353*** (0.14)	64148	0.82
I2410	1.257*** (0.12)	0.183 (0.13)	-0.758*** (0.09)	-0.069*** (0.02)	-3.377*** (0.16)	1.656*** (0.27)	0.132** (0.06)	-2.438*** (0.3)	3.275*** (0.36)	-1.931*** (0.18)	77231	0.86
I2420	0.951*** (0.12)	0.842*** (0.13)	-0.586*** (0.09)	-0.118*** (0.02)	-0.23 (0.16)	4.305*** (0.29)	-0.04 (0.07)	4.350*** (0.31)	3.515*** (0.36)	5.858*** (0.18)	74690	0.84
I25	0.821*** (0.07)	0.937*** (0.08)	0.002 (0.06)	-0.152*** (0.02)	-1.021*** (0.1)	1.787*** (0.19)	0.133*** (0.04)	2.485*** (0.19)	1.976*** (0.24)	3.198*** (0.12)	65124	0.77

Note: Robust standard errors in parenthesis. ***, **, and * indicates 1%, 5% and 10% level of significance respectively. All models include country and year fixed effects

Source: Prepared by the authors.

Table 4. Estimation Results of the Gravity Model for Export (1990-2021)

	GDPa	GDPb	RER	VOL	DIST	Contig	TA	Comcur	Colony	Comlang	N	R^2
Medium-High Technology	1.234*** (0.06)	0.667*** (0.07)	-0.186*** (0.06)	-0.081*** (0.01)	-1.017*** (0.09)	2.290*** (0.16)	0.103*** (0.04)	2.247*** (0.16)	2.432*** (0.21)	2.932*** (0.1)	81023	0.88
I20	1.034*** (0.08)	0.637*** (0.09)	-0.273*** (0.07)	-0.047** (0.02)	-1.397*** (0.11)	2.731*** (0.19)	0.081* (0.04)	1.801*** (0.2)	2.155*** (0.25)	2.176*** (0.12)	62192	0.77
I27	1.195*** (0.08)	0.858*** (0.09)	0.015 (0.06)	-0.154*** (0.02)	-0.943*** (0.11)	0.959*** (0.2)	0.170*** (0.04)	1.010*** (0.2)	2.673*** (0.26)	2.704*** (0.13)	77589	0.85
I28	1.359*** (0.07)	0.795*** (0.08)	-0.136** (0.06)	-0.071*** (0.02)	-0.738*** (0.09)	2.354*** (0.16)	0.099*** (0.04)	0.981*** (0.17)	2.930*** (0.22)	3.076*** (0.1)	77200	0.85
I29	1.389*** (0.1)	1.045*** (0.11)	-0.151** (0.08)	-0.097*** (0.02)	-0.693*** (0.14)	4.129*** (0.24)	0.128** (0.06)	6.868*** (0.25)	1.792*** (0.31)	6.943*** (0.16)	77222	0.86
I30	0.882*** (0.09)	1.156*** (0.12)	-0.283*** (0.08)	-0.091*** (0.02)	-0.966*** (0.14)	1.471*** (0.25)	-0.002 (0.06)	1.168*** (0.24)	3.606*** (0.31)	1.639*** (0.16)	78440	0.88
I3250	0.726*** (0.08)	0.991*** (0.1)	0.171** (0.07)	-0.133*** (0.01)	-0.514*** (0.11)	-2.618*** (0.16)	-0.012 (0.05)	0.221 (0.18)	2.823*** (0.27)	-1.536*** (0.09)	70047	0.84
High Technology	0.929*** (0.09)	1.370*** (0.1)	0.425*** (0.07)	-0.158*** (0.02)	-0.323*** (0.12)	0.572*** (0.2)	0.087* (0.05)	1.494*** (0.23)	0.791*** (0.26)	3.147*** (0.13)	78135	0.86
I21	0.324*** (0.1)	0.409*** (0.11)	-0.01 (0.07)	-0.090*** (0.02)	-0.491*** (0.12)	-0.17 (0.28)	-0.120** (0.06)	2.360*** (0.22)	2.329*** (0.22)	1.251*** (0.1)	62848	0.75
I26	0.984*** (0.09)	1.398*** (0.1)	0.438*** (0.07)	-0.164*** (0.02)	-0.471*** (0.13)	0.289 (0.21)	0.105** (0.05)	1.211*** (0.24)	0.834*** (0.27)	3.023*** (0.14)	64592	0.84

Note: Robust standard errors in parenthesis. ***, **, and * indicates 1%, 5% and 10% level of significance respectively. All models include country and year fixed effects.
Source: Prepared by the authors.

exchange rate movements and may even be adversely affected by higher import costs following depreciation (Braunerhjelm & Thulin, 2008). A stronger currency enables firms to upgrade product quality, which is especially crucial for high-technology sectors that compete on quality, reliability, and innovation (Amiti & Khandelwal, 2013). Appreciation can support import of superior inputs and technologies in these industries, facilitating upgrading.

Contrary to the sectoral effects of RER, the impact of VOL appears to exhibit limited variation across sectors. VOL has a significantly negative effect on the exports of almost all of the sectors with small variations in magnitudes as supported by the findings of Peridy (2003) and Byrne et al. (2008). Exporting firms tend to shift their activities to the domestic market in order to minimize the income uncertainty caused by ER fluctuations (Chowdhury, 1993; Doğanlar, 2002). This behavior can be explained by the expected utility maximization theory (Neumann & Morgenstern, 1990), which posits that firms seek to optimize their expected profits by turning to relatively stable domestic markets instead of riskier foreign markets. From another perspective, firms tend to postpone long-term investment and market entry decisions and adopt a wait-and-see strategy according to the real options theory of Dixit and Pindyck (1994).

The standard gravity variables in Table 4 largely conform to theoretical expectations. Domestic income (GDPa) positively affects exports in 15 of 20 sectors, while partner country income (GDPb) is positive and significant across all sectors. DIST negatively affects exports in almost all industries, though its impact is weaker for high-technology sectors, indicating that distance matters less for skill-intensive manufactures-consistent with Martin and Mayneris (2015), and Caglayan and Demir (2019). Moreover, the dummy variables-contiguity, trade agreements, common currency, colonial ties, and common language-generally display positive and statistically significant effects across most sectors.

4.3. Periodical Differences

The sample period covers major structural transformations in global production and trade. To identify period-specific differences, sectoral export equations are estimated separately for 1990-2005 and 2006-2021 (Table 5). The findings reveal substantial differences in the impact of RER changes between periods. In 1990-2005, a real depreciation significantly increases exports in all sectors, consistent with the expenditure-switching mechanism (Obstfeld & Rogoff, 2007). In the earlier period which GVC participation is more limited, traditional ER transmission mechanisms tend to operate and competitiveness effect of real depreciations is prominent for nearly all individual industries. Although the coefficients are uniformly positive, their magnitudes vary: high-technology sectors exhibit the lowest ER elasticity, while medium-low and medium-high technology industries show the highest responsiveness. This result is consistent with the findings of Berman et al. (2012), and Caglayan and Demir (2019) which suggest that higher-skill and higher quality products tend to be less responsive to ER fluctuations due to lower elasticity, higher profit margins, and broader market reach.

Table 5. Estimation Results of the Export Model for the Periods 1990-2005 and 2006-2021

	1990-2005		2006-2021	
	RER	**VOL**	**RER**	**VOL**
Low-Technology	-0.561***	-0.017	0.329***	-0.151***
I10-12	-0.669***	0.036*	0.327***	-0.162***
I13	-0.579***	-0.007	0.454***	-0.156***
I14	-0.455***	-0.099***	-0.201**	-0.177***
I15	-0.300***	-0.067***	0.286***	-0.225***
I16	-0.777***	-0.083***	-0.358***	-0.120***
I17	-0.531***	0.031	0.254**	-0.127***
Medium-Low Technology	-0.892***	-0.012	0.791***	-0.194***
I19	-0.687***	-0.017	0.307*	-0.058
I22	-0.550***	-0.015	0.395***	-0.134***
I23	-0.974***	0.005	0.263***	-0.115***
I2410	-1.245***	0.064***	0.326***	-0.113***
I2420	-0.947***	0.012	0.360***	-0.164***
I25	-0.584***	-0.056***	0.480***	-0.180***
Medium-High Technology	-0.823***	0.041**	0.480***	-0.190***
I20	-0.903***	0.079***	0.532***	-0.193***
I27	-0.674***	-0.037*	0.566***	-0.187***
I28	-0.764***	0.039**	0.480***	-0.183***
I29	-0.844***	0.059***	0.259***	-0.230***
I30	-0.591***	-0.018	0.023	-0.128***
I3250	-0.261***	-0.021	0.079	-0.188***
High Technology	-0.264***	-0.035*	0.546***	-0.161***
I21	-0.490***	0.028	0.320***	-0.169***
I26	-0.244***	-0.041**	0.525***	-0.165***

Source: Prepared by the authors.
Note: Robust standard errors in parenthesis. ***, **, and * indicates 1%, 5% and 10% level of significance respectively. All models include country and year fixed effects.

The analysis' results for the 2006-2021 period show that trade enhancing impact of depreciation prevails only for two sectors (I14 and I16) in the latter period, indicating that the traditional ER transmission mechanisms predicted by the Mundell-Fleming model remain valid for these industries. As demonstrated by Amiti and Weinstein (2011), and Baldwin and Gonzalez (2015), traditional ER transmission mechanisms tend to operate more prominently in sectors with low GVC integration. In particular, structural characteristics observed in these sectors such as low dependence on imported intermediate goods, high price elasticity of final products, and limited participation in global production networks can be considered as the key factors that increase their sensitivity to ER changes. However, in the 2006-2021 period, the traditional effects of the ER on sectoral exports have seemed to be reversed for many sectors. In 16 of the 20 sectors, the coefficient of bilateral RER turns from negative to positive in the latter period, while in 2 sectors the coefficient become statistically insignificant. As evident from the sectoral parameter estimates of the RER, the transformation in the structure in the global trade, due to the factors such as advances in information technologies, the expansion of GVCs and increased interdependence of global production processes have made the ER-trade link more complex. Ambiguous ER effects on industrial trade emerge in sectors with high import dependence in export production, since currency depreciation increases domestic export costs or prices. As emphasized by Jongwanich (2010), Ahmed et al. (2017), and Cheng et al. (2018), as sectors become more integrated into GVCs, the flexibility of the trade balance to ER shocks diminishes. According to Ollivaud et al. (2015) and Ahmed et al. (2017), the rising integration into GVCs largely explains the observed weakening in the ER-trade relationship. Our findings basically imply that the gains from depreciation of the currency can be offset or even outweighed by the losses due to the increased costs. This result is also consistent with the results of Kang and Dağlı (2018) which shows that while currency depreciations generally promote export growth, this effect has weakened-and in some cases even reversed-particularly after the Global Financial Crisis, partly due to the deepening of GVCs. Incomplete pass-through or 'pricing to market' (Krugman, 1987; Marston, 1990) can be another reason for this shift in the ER-trade relationship. The weakening of the relationship between RER movements and trade flows since the mid-2000s can be partly explained by the increasing prevalence of pricing-to-market behavior and incomplete exchange rate pass-through. Under pricing-to-market, firms with market power adjust their markups in response to exchange rate fluctuations rather than fully passing these changes into export prices, thereby stabilizing prices in destination markets (Krugman, 1987). This behavior is particularly pronounced in differentiated goods sectors, where exporters prioritize market share and price stability over immediate price competitiveness. Therefore, after a currency appreciation, exporters may adopt a price-to-market strategy, reducing prices in domestic currency terms to preserve their share in export markets (Fang et al., 2006).

Examining period-specific differences, the impact of VOL on sectoral exports is highly mixed in 1990-2005: the VOL coefficient is significantly positive in five sectors, negative in six, and insignificant in the others. By contrast, in 2006-2021, the coefficient of VOL is significantly negative in nearly all sectors. These results imply that amid expanding globalization, greater financial integration, and the widespread adoption of flexible ER regimes, VOL has emerged as a more substantial source of uncertainty and risk for manufacturing industries in recent decades. The rise of fragmented production may also make trade more sensitive to exchange rate risk. As emphasized by Ollivaud et al. (2015) and Ahmed et al. (2017), firms now operate within tightly coordinated cross-border production networks. As exports become increasingly dependent on imports, VOL increases cost uncertainty for both exports and imports. This makes exporters more sensitive to uncertainty, strengthening the negative effect of volatility. Additionally, as Clark et al. (2004) show that volatility reduces trade particularly when firms cannot fully hedge risk. In more complex modern trade structures, hedging can become costlier and less complete, especially with multi-currency exposure.

4.4. Robustness Checks

Potential endogeneity concerns related to the RER and VOL are mitigated in this type of sectoral analysis, as it is unlikely that unobserved factors would simultaneously and systematically influence both bilateral sector-level exports and the aggregate bilateral RER and VOL (Colacelli, 2008). Nevertheless, we also check for the possibility of endogeneity and examine whether our parameter estimates suffer from endogeneity bias. To this end, total manufacturing and sectoral export equations are re-estimated with Two Stage Least Squares Estimator (2SLS). In 2SLS estimations, home country's GDP (GDPa), RER and VOL are considered as endogenous and the first lags of these variables are used as instruments. 2SLS parameter estimates for total manufacturing and individual sectoral exports for the full sample, and the two sub-periods are reported in Table 6[11]. The results are generally similar to the fixed effects findings given in Table 3. Parameter estimates for the total manufacturing exports are given in the first raw of Table 6. In line with the fixed effects parameter estimates, the coefficient of RER is significantly negative in 1995-2005 period,

[11] We only report the main variables of interest RER and VOL in Table 6 in order to save space. Full table including the coefficients of all variables are available upon request.

while it becomes significantly positive in 2006-2021 period. Therefore, periodical differences in the response of exports to the RER is clearly evident in the 2SLS estimation results. Similar to the fixed effects estimation results, the coefficient of VOL is significantly negative in the second period while it is not statistically significant in the first period. When we compare the 2SLS estimates with those in Table 3, the only difference is that the coefficient of the RER becomes statistically insignificant in the full sample period. Considering the period-specific changes in the RER elasticity of exports driven by the transformation in global production and trade, it is not surprising that the RER coefficient turns out to be insignificant over the full sample period.

Table 6. 2SLS Estimates for Manufacturing Industry Export Equations

	Full Period (1990-2021)		1990-2005		2006-2021	
	RER	VOL	RER	VOL	RER	VOL
EXP	0.023 (0.07)	-0.186*** (0.03)	-0.755*** (0.08)	0.048 (0.04)	-0.755*** (0.08)	-0.656*** (0.04)
Low-Technology	0.113* (0.07)	-0.193*** (0.03)	-0.529*** (0.09)	-0.005 (0.04)	0.927*** (0.10)	-0.572*** (0.05)
I10-12	0.040 (0.08)	-0.109*** (0.04)	-0.835*** (0.10)	0.162*** (0.04)	0.966*** (0.12)	-0.624*** (0.06)
I13	0.106 (0.09)	-0.225*** (0.04)	-0.591*** (0.11)	-0.004 (0.05)	1.059*** (0.12)	-0.610*** (0.07)
I14	-0.001 (0.10)	-0.313*** (0.05)	-0.437*** (0.12)	-0.124** (0.05)	0.215 (0.17)	-0.555*** (0.09)
I15	0.452*** (0.10)	-0.330*** (0.05)	-0.231* (0.12)	-0.034 (0.05)	1.113*** (0.17)	-0.877*** (0.09)
I16	0.007 (0.10)	-0.266*** (0.05)	-0.686*** (0.12)	-0.176*** (0.05)	-0.052 (0.16)	-0.422*** (0.08)
I17	0.340*** (0.11)	-0.217*** (0.05)	-0.583*** (0.12)	0.072 (0.05)	0.735*** (0.16)	-0.454*** (0.09)
Medium-Low Technology	0.056 (0.10)	-0.243*** (0.04)	-0.928*** (0.10)	-0.004 (0.04)	1.700*** (0.14)	-0.772*** (0.07)
I19	-0.141 (0.17)	0.015 (0.07)	-0.797*** (0.24)	0.007 (0.08)	0.159 (0.26)	0.077 (0.14)
I22	0.347*** (0.07)	-0.275*** (0.03)	-0.570*** (0.09)	-0.005 (0.04)	1.071*** (0.12)	-0.544*** (0.07)
I23	-0.346*** (0.10)	-0.076* (0.04)	-1.249*** (0.12)	0.079* (0.05)	0.612*** (0.14)	-0.315*** (0.07)
I2410	-0.688*** (0.13)	-0.154*** (0.05)	-1.388*** (0.16)	0.130** (0.06)	0.787*** (0.16)	-0.337*** (0.08)
I2420	-0.390*** (0.13)	-0.281*** (0.06)	-1.044*** (0.16)	0.040 (0.06)	1.173*** (0.19)	-0.712*** (0.10)
I25	0.325*** (0.08)	-0.369*** (0.04)	-0.496*** (0.10)	-0.162*** (0.04)	1.241*** (0.13)	-0.687*** (0.07)
Medium-High Technology	-0.005 (0.07)	-0.180*** (0.03)	-0.867*** (0.09)	0.082** (0.04)	1.249*** (0.10)	-0.682*** (0.05)
I20	-0.140 (0.09)	-0.133*** (0.04)	-1.006*** (0.11)	0.137*** (0.04)	1.355*** (0.12)	-0.742*** (0.07)
I27	0.259*** (0.08)	-0.318*** (0.04)	-0.693*** (0.11)	-0.069 (0.04)	1.153*** (0.13)	-0.574*** (0.07)
I28	0.026 (0.08)	-0.147*** (0.03)	-0.866*** (0.10)	0.101** (0.04)	1.225*** (0.10)	-0.607*** (0.05)
I29	-0.025 (0.10)	-0.129*** (0.05)	-1.144*** (0.14)	0.258*** (0.06)	0.905*** (0.15)	-0.646*** (0.08)
I30	-0.159 (0.11)	-0.151*** (0.05)	-0.473*** (0.16)	-0.037 (0.06)	0.233 (0.19)	-0.277*** (0.10)
I3250	0.430*** (0.09)	-0.271*** (0.04)	-0.320*** (0.11)	0.007 (0.04)	0.789*** (0.14)	-0.680*** (0.08)

High Technology	0.784*** (0.08)	-0.310*** (0.04)	-0.130 (0.11)	0.009 (0.04)	1.176*** (0.12)	-0.550*** (0.07)
I21	0.147 (0.10)	-0.184*** (0.05)	-0.783*** (0.15)	0.123** (0.06)	0.988*** (0.15)	-0.659*** (0.08)
I26	0.808*** (0.09)	-0.318*** (0.04)	-0.087 (0.11)	0.005 (0.04)	1.140*** (0.13)	-0.550*** (0.07)

Source: Prepared by the authors.
Note: Robust standard errors in parentheses. ***, **, and * indicate 1%, 5% and 10% level of significance, respectively. EXP represents total manufacturing exports. All models include country and year fixed effects.

The coefficient estimates of RER and VOL for individual sectors are quite similar to the fixed effects results, particularly for the two sub-periods. For the full period, the coefficient estimate of RER does not follow a clear pattern in general. The parameter estimates of RER is significantly negative for 3 sectors, positive for 6 sectors, and not statistically significant for 11 of 20 industries. The ambiguous pattern observed in the effect of the RER on exports in the whole period estimates, can be attributed to structural transformations in global production and international trade over this period. When the sample period is split into two sub-periods, the sector-level impact of global developments on the RER-trade relationship becomes more clearly evident.

Consistent with previous findings, the coefficient of RER is significantly negative for almost all manufacturing industries in the 1995-2006 period. In line with the conventional Mundell-Fleming framework, 2SLS estimates support the trade enhancing effects of real depreciations in the earlier period. However, the coefficient of RER turns to positive, except for the three sectors from low and medium-low technology industry, in the latter period. The increased use of imported inputs associated with GVC participation which is the case especially for medium-high and high technology sectors, makes imports a prerequisite for exporting. Therefore, our findings suggest that an appreciation of the national currency reduces the cost of imported inputs, thereby increasing production and exports, which is also shown by Goda et al. (2024) and Sierra and Manrique (2014).

The 2SLS parameter estimates of VOL are highly consistent with the previous fixed effects estimations. The coefficient of VOL is significantly negative for all sectors in the full and 2006-2021 period, while it is not statistically significant for the major part of the industries in the 1995-2006 period.

Finally, the time period of the study covers a number of economic crisis such as Asian Financial Crisis (1997-1998), Global Financial Crisis (2007-2009) and COVID-19 Pandemics (2019-2020). Even though we add time effects to control for the effects of global shocks on exports, we also check whether these crises lead any bias on the parameter estimates. Therefore, export equation for the total manufacturing exports and individual industry exports for the full period are re-estimated by including three crisis dummies into the equations. The results do not change when crisis dummies are added to the analysis confirming the success of time effects in fixed effects methodology to capture the effects of common global shocks.

5. Conclusion

This study examines the ER-trade nexus at the industry-level bases focusing on the manufacturing industries of a large panel data of countries. We investigate whether the changes both in the level and the volatility of ERs vary across manufacturing sub-sectors considering also the periodical differences. Our export gravity model estimations mainly reveal that the effect of ER movements can change significantly across industries and over time. Our findings mainly indicate that for the full sample period and aggregate manufacturing trade, a real depreciation of the domestic currency tends to stimulate foreign trade by increasing total manufacturing exports in line with conventional economic theory. By contrast, VOL has a negative and statistically significant impact on total manufacturing exports. Our industry-by-industry analyses reveal that, during the 1990-2005 period, currency depreciation generally stimulated exports across nearly all manufacturing sub-sectors. By contrast, in the 2006-2021 period, these effects become statistically insignificant or are even reversed in most industries, with the exception of traditional labor-intensive sectors such as Apparel and Wood and cork products. This change is particularly pronounced in high-technology-intensive industries, notably Computer, electronic and optical products. Moreover, whereas VOL exerted only a limited influence on sectoral trade in the 1990s, its adverse effects on exports became substantially stronger from the 2000s onward.

Industrial characteristics such as the production structure, level of technological intensity, the use of imported inputs, and the degree of integration into global value chains (GVCs) may lead to substantial differences in the sectoral responses of trade flows to ER fluctuations. Our results show that empirical analyses based on aggregated data may produce misleading results by ignoring the different reactions of various sectors to macroeconomic variables. These differences make sectoral analysis essential for policymakers to take effective measures. Otherwise, macro-level generalizations may conceal opposing effects across sectors, leading to inaccurate conclusions.

Future research could contribute to the literature by further extending the model to allow for separate estimations based on countries' geographical locations or levels of economic development, thereby shedding light on the heterogeneity of the findings. In addition, computing indicators that capture the degree of integration into GVCs and incorporating them into the model, could provide a deeper understanding of the effects of ER movements on sectoral trade.

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11. Data Availability Statement: The dataset analyzed in this research is publicly accessible and its characteristics are described in detail in the manuscript.

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APPENDIX:

Table A.1. Variable description and data sources.

Variable	Definition	Code	Data source
Manufacturing export	Real exports of the total manufacturing (or by 20 manufacturing sub-sectors)	EXP	OECD STAN
GDP of the exporting country	Economic size of the exporting country (supply capacity)	GDPa	World Bank
GDP of the importing country	Economic size of the importing country (demand capacity)	GDPb	World Bank
Bilateral real ER	Purchasing power indicator	RER	BIS, IFS-IMF
Volatility of the real bilateral ER	Standard deviation of monthly real bilateral ERs	VOL	
Distance between the capitals of the two countries (km)	Transportation costs	DIST	CEPII
Contiguity	1 if countries share a common border, 0 otherwise	Contig	CEPII
Trade agreement	1 if countries are members of the same trade agreement, 0 otherwise	TA	CEPII
Currency union	1 if countries share the same currency, 0 otherwise	Comcur	CEPII
Historical tie	1 if countries have a historical colonial relationship, 0 otherwise	Colony	CEPII
Cultural proximity	1 if countries share an official or widely spoken language, 0 otherwise	Comlang	CEPII
Country-pair	Country-pair fixed effects	δ_{ab}	
Time effects	Year specific time fixed effects	γ_t	

Source: Prepared by the authors.