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Effects of Real Exchange Rate Volatility on Trade: Empirical Analysis of the United States Exports to BRICS

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Abstract: This paper analyzes the effects of real exchange rate volatility on the United States' exports to BRICS. It focuses on the top 20 export products (defined by the 2-digit Harmonized System codes) from the United States to Brazil, Russia, India, China, and South Africa, and uses quarterly data for period from 1993Q1 to 2021Q2. The specified panel regression model was first estimated using three estimation methods, namely, the Panel Least Squares, the Panel Fully Modified Least Squares (FMOLS), and Panel Dynamic Least Squares (DOLS). In addition, to estimate the short-run and long-run effects of real exchange rate volatility on exports, it also uses the method of the Autoregressive Distributed Lag (ARDL) approach to cointegration analysis and error-correction models. Two measures of exchange rate volatility are used in this study. According to our findings, the levels of foreign economic activity have a positive effect on exports while the real exchange rate has a negative effect on exports. In addition, exchange rate volatility has a negative effect on exports in the long run in all five countries. However, the effects of exchange volatility are found to yield mixed results in the short run regardless of which measure of exchange rate volatility was used.

Keywords: BRICS; exports; real exchange rate volatility; GARCH volatility measures; panel data models; panel cointegration

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1. Introduction

Much theoretical and empirical research has been conducted to examine the effects of exchange rate volatility on international trade flows. However, no real consensus about the impact of exchange rate volatility on trade has emerged despite the sizeable number of studies conducted. The majority of empirical investigations have discovered that exchange rate volatility has a negative impact on trade flows. One of the reasons for the negative relationship between exchange rate volatility and trade flows is that real exchange rate volatility may affect exports directly through uncertainty and adjustment costs for risk-averse exporting investors. Another reason for the negative relationship is that exchange rate volatility may have an indirect effect through its impact on output structure, investment, and government policy. Exchange rate volatility and trade flows have been found to have a positive relationship in some studies, while a few other studies have found an insignificantly negative association between the two variables. A positive association between the two variables has been attributed to exchange rate volatility making exporting more appealing to risk-tolerant exporting firms.

Some of the reasons for contradictory results by different studies include: the differences in the way exchange rate volatility was measured; the various types of sample data that were used such as aggregate export data or sectoral export data; the use of different timeframes; and the use of different econometric methods. Recent research studies have begun investigating the nexus between exchange rate volatility and exports from a sectoral viewpoint, thanks to improved access to sectoral data and the development of more sophisticated econometric methods. Because the different trade sectors are impacted differently

by exchange rate volatility, the results of studies that employ sectoral trade data may be more enlightening than those that use aggregate data.

The focus of this research is on exports from the United States to the five countries in BRICS (Brazil, Russia, India, China, and South Africa) of its top 20 export products, to better understand the nature and sensitivity of the link between exchange rate volatility and exports. The top 20 export products to each country account for the majority of the U.S. total exports. For example, in 2020, the top 20 export products of the United States accounted for 76% of exports to Brazil, 83% of exports to China, 67% of exports to India, 77% of exports to Russia, and 76% of exports to South Africa. Both the panel cointegration and the Autoregressive Distributed Lag (ARDL) approach to cointegration analyses are used in this study to investigate the effects of exchange rate volatility on exports. The study focuses on a period of 28 years, using quarterly data from 1993Q1 to 2021Q2.

The following is a breakdown of the paper's structure: Section 2 presents the review of literature, Section 3 presents the methodology and data sources, after which, Section 4 presents empirical results and the discussion of the results, and Section 5 summarizes our conclusions.

2. Literature Review

There is a significant body of literature available on the effects of exchange rate volatility in numerous countries such as the United States, the United Kingdom, Australia, Canada, India, Pakistan, China, Korea, Indonesia, Nigeria, Thailand, Malaysia, Mexico, Turkey, and Ghana. In this section, we provide a summary of studies that explore the relationship between exchange rate volatility and trade. We start with the most recent and advanced investigations, which include cointegration techniques and error-correction models, and then move on to previous, less complex studies. For a comprehensive review of empirical studies, see Bahmani-Oskooee and Hegerty (2007).

Tunc and Solakoglu (2016) examine how the volatility of exchange rates effect foreign sales of firms using destination-specific U.S. firm-level data. Different quantiles of the conditional distribution have also been considered in exploring the data. The study has found that firm size, economic conditions, firm characteristics, operating sector, quantile of the conditional distribution, and foreign market dependence are influential on foreign sales when the exchange rates are volatile. The study suggested using aggregated data using mean-regression methods, ignoring firm-specific factors to explain mixed results as in the literature. Chi (2020) performed a study to investigate the possible asymmetric exchange rate effects on cross-border freight flows between the United States and Canada. Linear and nonlinear auto regressive distributed lag models have been used to analyze the data. Evidence has been found that both exchange rate volatility and currency value affect the freight flows of US and Canada in an asymmetric manner. The findings of this study suggested that asymmetric effects of exchange rate on cross-border freight flows are misled by the conventional linear specification. Bahmani-Oskooee and Aftab (2017) have also found the asymmetric effects of exchange rate volatility on trade flows. The study utilized monthly data from 117 Malaysian industries out of which 54 have exported to and 63 have imported from the USA. The study found that most industries are responsive to the volatility of real exchange rates.

It is unarguably worth studying the effects of exchange rate volatility on trade in China, as it is the largest exporter in the world. Many studies have been performed based on China. Smallwood (2019) conducted a study to analyze the impact of exchange rate uncertainty on bilateral export growth for China's ten export markets. Flexible multivariate DCC-GARCH model was used in the study utilizing a comprehensive sample of data from 1994–2017. It was found that exchange rate uncertainty has no impact on U.S. trades, while there is impact for all remaining countries. Another study was performed by Chen et al. (2020) to investigate the impact of uncertainty of economic policies on volatility of exchange rates in China utilizing data from 2001 to 2018. Quantile regression was used for the analysis. The results of the study showed an asymmetric and heterogenic

relationship between economic policy uncertainty and exchange rate volatility in China. Bahmani-Oskooee and Kanitpong (2019) have estimated both linear and nonlinear Autoregressive Distributed Lag (ARDL) import and export demand models for 45 industries that trade between China and Thailand. The result from the nonlinear model showed that the short-term asymmetric effects are evident on the trade flows of all industries due to uncertainty of exchange rates. Further, the study showed that 50% of the industries are affected in the long term, as the short run asymmetric effects lasted for a long time. Hurley and Papanikolaou (2021) examined US–China trade dynamics with special concentration on leading commodity imports and exports. Quarterly data covering the period 2000Q1–2016Q4 were used to analyze the effect of real income of both countries, bilateral real exchange rates and the volatility of the exchange rates, US investment, exchange risk effect of the "third country", and the role of human capital investment and financial deepening. The Autoregressive Distributed Lag (ARDL) model was used to analyze data. Evidence of the study suggested that most of the bilateral commodities traded between the two countries are responsive to the changes in real exchange rates. Further, the study found impacts of appreciation and depreciation of both currencies on commodity trades.

Bahmani-Oskooee and Karamelikli (2021a) assess the effects of real yuan-pound uncertainty on imports and exports between the U.K. and China. Industry-specific findings were received by the analysis, but in general terms, the study identified that increased exchange rate volatility discouraged U.K. exports to China in most industries, while Chinese export to the U.K. was encouraged in most industries. On the other hand, it was identified that the decreased exchange rate volatility encouraged exports of the U.K. industries and discouraged the exports of some Chinese industries. The same authors performed another study, Bahmani-Oskooee and Karamelikli (2021b), to assess the responsiveness of trade flows between the U.K. and Germany to volatility of exchange rates. Linear and nonlinear export demand models were used for the analysis of this study. The nonlinear export demand model found that short-term asymmetric effects of exchange rate volatility were shown for a higher number of industries which lasted into long-term asymmetric effects than in linear models.

Sharma and Pal (2018) performed a study that offered commodity level evidence regarding the effects of volatility of exchange rates on India's cross-border trades with China, Japan, Germany, and the USA. Autoregressive conditional heteroscedasticity-based models and pooled mean group estimators were used to estimate the nominal exchange rate volatility. The results showed that nominal exchange rate volatility has a significant deterrent impact on export rates of India to China, Germany, and the USA in the long term, together with import from China and the USA. However, the short-term effects were rather mixed, and no asymmetric effect was shown by the results. Conversely, Bahmani-Oskooee and Saha (2021) have found that short-term asymmetric effects that are translated to long-term effects existed for most of the trade flows when the exchange rates are volatile. The study was based on impact of exchange rate volatility on India's trade flows to and from its largest trading partners.

Chi and Cheng (2016) have attempted to examine the short- and long-term impacts of real income, bilateral exchange rate, and volatility of exchange rate on maritime export volume of Australia to its major trading partners, namely China, the Republic of Korea, Japan, Taiwan, India, Malaysia, and Indonesia. Quarterly data from 2000Q1 to 2013Q2 was used for the analysis. Generalized Autoregressive Conditional Heteroscedasticity (GARCH) and mean adjusted relative change measures were included as two measures of real exchange rate volatility for comparison purposes. The study found that real income is a paramount factor of maritime export volume. Further, the study found that exchange rate volatility is also a paramount factor that affects maritime export volume. Bahmani-Oskooee et al. (2016) conducted a study analyzing 60 Pakistani import industries from Japan and 44 Pakistani export industries to Japan. Pakistan–Japan trade flows have been considered disaggregating by commodity to remove aggregation bias. The results obtained by Bahmani-Oskooee et al. (2016) were different from the findings of other stud-

ies. Their research found that not many industries are affected by volatility of exchange rates. Kim (2017) performed a study using monthly data from 2000M1 to 2015M12 and analyzed the effects of the volatility of exchange rate (USD/KRW) on seaborne import volume in Korea. The Autoregressive Distributed Lag (ARDL) model was used to analyze the data. The results of the study showed that a statistically significant negative influence existed between USD/KRW exchange rate volatility and Korea's seaborne import volume. Further, it was found that the volatility of USD/KRW exchange rate exhibited short-run unidirectional causality on real income and import volume, from the results of a Vector Error Correction Model (VECM). The evidence has confirmed a bidirectional causality between the real effective exchange rate and volatility of exchange rate.

Sugiharti et al. (2020) performed a study to analyze the impact of volatility of exchange rates on Indonesia's export destinations to China, India, South Korea, Japan, and the USA. The study used data from 2006 to 2018 and utilized the GARCH and ARDL models. The results at the aggregate level showed that exports are positively related with industrial production for India, China, and South Korea, while the USA and Japan were not significant. Further, the results suggested that depreciation of the Rupiah has discouraged exports to China, South Korea, and the USA, while only exports to Japan are encouraged by depreciation of the Rupiah. The long-term estimates suggested that exchange rate volatility discouraged exports to Japan, India, South Korea, and the USA, but encouraged exports to China. However, the results of the exchange rate volatility at the commodity level are mixed. Yunusa (2020) examined the effect of volatility of exchange rate on Nigerian crude oil export to its trading partners, namely, UK, USA, France, Italy, Canada, Spain, and Brazil. Monthly data from 2006M1 to 2019M12 were used for the study utilizing the GARCH and ARDL models. The results of the study showed that the exchange rate volatility between Nigeria and its trading partners is crucial in deciding crude oil exportation volume made by Nigeria to its trading partners. Finally, the results suggested that exchange rate volatility significantly influenced crude oil exportation in Nigeria. Results of the study performed by Arize et al. (2021) show the presence of cointegration and negative effects of exchange rate risk on the volume of exports from Thailand in both long and short-term using a nonlinear, asymmetric Autoregressive Distributed Lag (ARDL) model. Another study was conducted by Aftab et al. (2016) to investigate the sensitivity of exchange rate risk of Malaysian bilateral trade flows with Japan, which is one of its most important trading partners. Findings suggested that over one-third of the total co-integrated import and export industries experience the ringgit/yen sensitivity effect in the short term. However, results suggested that this effect persists in a smaller number of import and export industries in the long term. More importantly, the results concluded that the exchange rate risk has encouraged trade flows in most of the affected industries.

Bahmani-Oskooee et al. (2012) performed a study using the "bounds testing" cointegration approach from 1973 to 2006 to examine the effect of exchange rate volatility on trade flows between two countries of the North American Market, namely, Canada and Mexico. Results indicated that a decline in trade volumes were observed due to exchange rate volatility only for a few industries in the long term, as the multinational producers are able to hedge against exchange rate risk. One important implication from the study is that Mexico might have a stronger inducement to decrease volatility of its currency, the peso, if it wishes to encourage its exports. Nazlioglu (2013) investigated the effect of exchange rate volatility on export in Turkey. Data from Turkey's major export trading partners from 1980 to 2009 have been analyzed using panel cointegration analysis. The study found that the effect of exchange rate volatility on exports in Turkey has differed across industries. It also found that Turkey benefitted from the depreciation of its currency "lira". Finally, it concluded that foreign income plays a major role in deciding the industry level exports in Turkey. Osei-Assibey (2017) evaluated exactly how importers and exporters are incentivized either similarly or differently by cost of exchange rate volatility. It was found that import decisions are negatively affected by volatility of exchange rates in Ghana, as Ghanian exporters are risk-averse in the presence of higher exchange rate volatility and the

absence of hedging facilities. Finally, it was concluded that the relationship between total trade and volatility reflects the different responses by Ghanian importers and exporters to higher costs of exchange rate volatility.

Regional studies can be found in the literature relating to the effects of exchange rate volatility. Examples include Sub-Saharan Africa and South America. Senadza and Diaba (2017) apply the pooled-mean group estimator of dynamic heterogeneous panels technique to analyze data for eleven Sub-Saharan African economies from 1993 to 2014. The results of the study uncovered that there are no significant impacts of exchange rate volatility in terms of imports. In contrast, a negative impact of volatility on exports was found in the short term, while a positive impact was found in the long term. Bahmani-Oskooee and Gelan (2018), using data for twelve African countries, investigated the effect of real exchange rate volatility on their imports and exports. The bounds testing approach was utilized for the analysis. The results found that trade flows of many countries are affected by exchange rate volatility in the short term, but only a few countries are affected in the long term in both imports and exports. As per an article written by Serenis (2013) to examine the effect of exchange rate volatility on the exports of Bolivia, Guyana, and Colombia, which are three South American countries, it was found that a significant negative relationship existed between volatility and aggregate exports.

Asteriou et al. (2016) analyzed the impact of exchange rate volatility on international trade volumes for MINT (Mexico, Indonesia, Nigeria, and Turkey) countries. The GARCH model (Generalized Autoregressive Conditional Heteroscedasticity), ARDL (Autoregressive Distributed Lag) bound testing approach, and Granger causality models were utilized for the analysis. Results from the analysis showed that no relationship existed between volatility of exchange rate and international trade except for Turkey in the long run, while a significant causal relationship between volatility and international trade was detected for Indonesia and Mexico in the short run. Further, a unidirectional causality between export demand and volatility was found in the case of Nigeria, while no causality was found between volatility and international trade for Turkey. Lin and Su (2020) applied daily data from August 2005 to February 2019 to analyze the effect of oil price shocks on the exchange rates of BRICS (Brazil, Russia, India, China, and South Africa) countries. The Ensemble Empirical Mode Decomposition (EEMD) method, Autoregressive Distributed Lag (ARDL) approach, Vector Autoregression (VAR) model, and a new framework were utilized to analyze data. Evidence suggested that different effects on net oil importing and exporting countries can be produced by two oil price shocks. Further, the results from different frequencies showed that exchange rates have a significant relationship to oil shocks only at a high frequency. Uniqueness was shown by China among the countries of BRICS, because the response to oil price shocks by Chinese exchange rates was found as insignificant compared to other countries.

Lin et al. (2018) examined the role of credit constraints in deciding the trade impact of exchange rate volatility. Evidence suggested that exchange rate volatility has a significant negative effect on constrained firms. To be precise, the results showed that more negative exposure of trade volumes to volatility of exchange rates is exhibited by financially more-constrained sectors. Further, it is found that the estimated trade impacts of exchange rate volatility vary significantly across sectors, and the direction is dependent on the degree of credit constraints.

The current study uses quarterly exports data covering a 28-year period from 1993Q1 to 2021Q2. The panel cointegration method and the ARDL approach to cointegration analysis were employed in this study, which may reveal the nature and sensitivity of the real exchange rate volatility-exports nexus.

3. Methodology and Data

3.1. Model Specification

This paper analyzes the effects of real exchange rate volatility on the United States' exports to BRICS. The study examines the nature and sensitivity of the link between exchange

rate volatility and exports using quarterly data of exports to five countries in BRICS, focusing on the top 20 export goods from the U.S. to each country. We stipulate that a standard long-run reduced-form export demand function have the following functional form, based on the current empirical research (see, for example, Bahmani-Oskooee and Kanitpong 2019; Ozturk and Kalyonku 2009; and Arize et al. 2021):

$$\ln X_{i,\,t} = \beta_0 + \beta_1 t + \beta_2 lnRER_t + \beta_3 lnY_t + \beta_4 lnV_t + \varepsilon_t \quad (1)$$

where $X_{i,t}$ is the real export volume of product i in period t (i = 1, 2, . . . , 20; t = 1, 2, . . . , 114), t represents the linear trend, RER_t is the real exchange rate in period t, Y_t is the real foreign income in period t, V_t is a measure of exchange rate volatility, and ε_t is a white-noise disturbance term.

An increase in the real exchange rate implies that the domestic currency is appreciating, which reduces exports, whereas a fall in the real exchange rate implies that the domestic currency is depreciating, which increases exports. Therefore, the expected sign of β_2 is negative. According to economic theory, the real income level of a country's trading partners has a positive impact on demand for its exports. Hence, the expected sign of β_3 is positive. Various measures of exchange rate volatility have been proposed in the literature. As explained in Section 3.2 below, this study uses two alternative measures of exchange rate volatility. Since the impacts of exchange rate volatility on exports have been found to be equivocal both empirically and conceptually (Bredin et al. 2003), the expected sign of β_4 could either be positive or negative.

The long-run relationship among the variables in our specified model is presented in Equation (1). First, the Panel Least Squares, the Panel Fully Modified Least Squares (FMOLS), and the Panel Dynamic Least Squares (DOLS) estimation methods were used to estimate the specified panel regression model. Furthermore, given recent developments in time-series analysis, it is now normal practice to differentiate short-run impacts from long-run effects when estimating the long-run model defined by Equation (1). This requires specifying Equation (1) in an error-correction modeling (ECM) format. Many recent studies have used this method, including the recent studies by Pino et al. (2016); Bahmani-Oskooee and Gelan (2018); Bahmani-Oskooee and Kanitpong (2019); Bahmani-Oskooee and Saha (2021); and Hurley and Papanikolaou (2021). According to Bahmani-Oskooee and Wang (2008), such an approach is justified when one variable, such as the exchange rate volatility, is a stationary while the other variables in Equation (1) could be non-stationary. Hence, we use the autoregressive distributed lag approach to cointegration analysis, or the method of bounds testing introduced by Pesaran et al. (2001), to rewrite Equation (1) as an ARDL-ECM model in Equation (2) below.

$$\begin{aligned} \Delta lnX_t = \rho_0 \; &+ \rho_1 t + \sum_{j=1}^{p} a_i \Delta lnX_{t-j} + \sum_{j=0}^{p} \gamma_i \Delta lnRER_{t-j} + \sum_{j=0}^{p} \delta_i \Delta lnY_{t-j} \\ &+ \sum_{j=0}^{p} \theta_i \Delta lnV_{t-j} + \pi_0 X_{t-j} + \pi_1 RER_{t-j} + \pi_2 Y_{t-1} + \pi_3 V_{t-1} + \varepsilon_t \end{aligned} \quad (2)$$

where Δ is the difference operator, p is the lag length, and ϵ_t is a random error term. The bounds testing approach to cointegration introduced by Pesaran et al. (2001) involves two procedural steps. The first step requires testing for joint significance of the no cointegration hypothesis H_o: $\pi_0 = \pi_1 = \pi_2 = \pi_3 = 0$ against an alternative hypothesis of cointegration, H_1: $\pi_0 \neq 0$, $\pi_1 \neq 0$, $\pi_2 \neq 0$, $\pi_3 \neq 0$ using an F-test or Wald test. The benefit of this method is that it eliminates the necessity to test for unit roots, which is typical in cointegration analysis. Two sets of critical values for a given level of significance with and without a time trend are provided by Pesaran et al. (2001). One set is developed assuming that the variables are stationary at the levels, or I(0), and the other set is developed assuming that the variables are stationary at the first difference, or I(1). The null hypothesis (H_0) is rejected if the computed F-values surpass the upper critical limits value, indicating that the variables are co-integrated. Likewise, we fail to reject H_0 if the computed F-value is below the critical

bounds values, indicating that the variables are not co-integrated. Finally, the result is considered inconclusive if the computed F-statistic falls between the lower and upper bound values. It is important to point out that this approach is applicable when we use time-series data. In this study, we use panel data covering 20 industries and 114 quarters for each of the five countries, and, therefore, cointegration among variables was tested using Pedroni's heterogeneous panel cointegration test, as outlined in Pedroni (1999). The second phase involves estimating the following error-correction model to assess short-run impacts after establishing the presence of cointegration.

$$\Delta lnX_t = \rho_0 + \rho_1 t + \beta\varepsilon_{t-1} + \sum_{j=1}^{k} \alpha_i \Delta lnX_{t-j} + \sum_{j=0}^{k} \gamma_i \Delta lnRER_{t-j} + \sum_{j=0}^{k} \delta_i \Delta lnY_{t-j} + \sum_{j=0}^{k} \theta_i \Delta lnV_{t-j} + \vartheta_t \quad (3)$$

where ε_{t-1} is the lagged residual of the cointegration relationship from the model in Equation (1), and ϑ_t is a white-noise disturbance term. The lag length k is initially set to 4 lags, but insignificant coefficients were successively dropped until the best fit model was found.

3.2. Defition of Variables and Data Sources

Each country's export data set spans 28 years, from 1993Q1 to 2021Q2, resulting in 114 quarterly observations. The source of the quarterly data on exports was the U.S. Department of Commerce. Quarterly data on nominal export volumes were converted to real export volumes using export price indices, with 2010 as the base year (=100). The study focuses on the top 20 export goods from the U.S. to each of country. The top 20 U.S. export products for each of the five countries are presented in Appendix A, Table A1.

The real income variable for each country is proxied by the industrial production index (2010 = 100). The data on industrial production index were collected from the *International Financial Statistics* database of the International Monetary Fund and from the online database of the Organization for Economic Cooperation and Development.

Following Hurley and Papanikolaou (2021) and Rodrik (2008), the real exchange rate between the U. S. dollar and the currency of trading partner i, RER_i, is constructed as:

$$RER_i = \frac{CPI_{US} \times NER_i}{CPI_i} \quad (4)$$

where NER_i is the nominal bilateral exchange rate defined as the number of foreign currency units per U.S. dollar, CPI_{US} is the price level in the United States, and CPI_i is the price level in country i. Price levels in both countries are measured using the consumer price index, CPI (2010 = 100). The data on nominal exchange rates and CPI for each country are sourced from the *International Financial Statistics* database of International Monetary Fund.

This research utilizes two distinct measures of exchange rate volatility, each obtained from the real exchange rate defined in Equation (4). The estimated conditional variance of a GARCH (1,1) model was used to generate our first measure of exchange rate volatility. Although some earlier studies have employed nominal exchange rates, real exchange rates were used in this study to calculate our measure of exchange rate volatility. By imposing an autoregressive structure on the process's squared errors, the GARCH model allows for persistence in conditional variance. The ARCH-type models, according to Choudhry (2005), capture time-varying conditional variance as a parameter created from a time-series model of the conditional mean and variance of the growth rate, and hence are highly useful in capturing volatility clustering. Other measures of exchange rate volatility may overlook information about the stochastic processes that generate the volatility in exchange rates.

The GARCH (1,1) model that we estimate is based on an autoregressive model of the first difference of the real exchange rate of order 1, and it takes the following structure:

$$RER_t = \alpha_0 + \alpha_1 RER_{t-1} + \varepsilon_t \qquad \text{where } \varepsilon_t \sim N\left(0,\ h_t^2\right) \tag{5}$$

$$h_t^2 = \beta_0 + \beta_1 \varepsilon_{t-1}^2 + \delta_1 h_{t-1}^2 \tag{6}$$

Our first measure of exchange rate volatility is derived as the estimated conditional variance (h_t^2) from Equation (6), i.e., $VOL_{1t} = h_t^2$.

Following Bredin et al. (2003); Moslares and Ekanayake (2018); and Chowdhury (1993), we construct our second measure of real exchange rate volatility. The real exchange rate volatility measure is developed as follows, according to these authors:

$$VOL_{2t} = \left[\frac{1}{m}\sum_{i=1}^{m}(lnRER_{t+i-1} - lnRER_{t+i-2})^2\right]^{\frac{1}{2}} \tag{7}$$

where VOL_{2t} is our second measure of real exchange rate volatility, RER_t is the real exchange rate defined in Equation (4), and m is the order of the moving average. We have set the value of m at 4 (m = 4). This measures the standard deviation of the moving average of the logarithm of the real exchange rate, and it is capable of capturing long-term changes in real exchange rate volatility and risk.

4. Empirical Results

4.1. Summary Statistics

The major findings and empirical results of the study are discussed in this section. We start with a discussion of the summary statistics of the variables used in the specified model that are presented in Table 1. The level of real exports is largest in China, followed by Brazil and India. South Africa shows the lowest level of exports from the United States. There is a significant difference between the values of two exchange rate volatility measures. The volatility measure derived using GARCH (1,1) model shows much larger values than those derived using the standard deviation of the moving average of the logarithm of the real exchange rate. Russia and India have the highest values for each measure.

Table 1. Summary Statistics (1993Q1–2021Q2).

Country/Statistic	*REX*	*RER*	*Y*	VOL_1	VOL_2
Brazil					
Mean	198.58	1.64	111.69	8.57	0.03
Median	63.70	1.59	112.49	1.31	0.02
Maximum	1982.40	3.18	142.97	96.81	0.08
Minimum	0.00	1.03	75.08	0.00	0.01
Std. Deviation	34.74	0.46	16.15	17.63	0.02
China					
Mean	578.82	7.29	99.49	1.88	0.02
Median	158.10	7.03	98.98	1.33	0.01
Maximum	7046.00	8.89	105.56	5.56	0.05
Minimum	0.30	5.92	84.37	0.02	0.01
Std. Deviation	938.24	0.81	4.11	1.70	0.01
India					
Mean	82.26	38.17	118.32	46.47	0.01
Median	27.68	39.50	125.54	27.19	0.01
Maximum	1543.70	47.64	192.82	159.49	0.06
Minimum	0.00	29.51	52.88	0.53	0.01
Std. Deviation	141.99	5.55	32.79	45.92	0.01

Table 1. *Cont.*

Country/Statistic	*REX*	*RER*	*Y*	VOL_1	VOL_2
Russia					
Mean	37.61	34.25	138.32	115.13	0.10
Median	6.65	18.37	138.68	20.50	0.02
Maximum	624.00	606.46	211.82	660.20	1.31
Minimum	0.00	1.57	42.47	1.40	0.01
Std. Deviation	81.86	67.40	34.42	153.79	0.24
South Africa					
Mean	35.20	6.62	107.51	2.80	0.03
Median	12.35	4.41	108.73	1.05	0.02
Maximum	413.20	10.81	127.05	26.66	0.12
Minimum	0.00	4.38	81.00	0.00	0.01
Std. Deviation	59.60	1.44	10.91	4.21	0.02

Note: This table summarizes the statistics for the five countries in BRICS based on data for 20 export products and 114 quarters. *REX* is the real exports by industry, measured in millions of 2010 dollars; *RER* is the real exchange rate; *Y* is the real foreign income as proxied by industrial production index (2010 = 100); VOL_1 is the exchange rate volatility measured using Equations (5) and (6); and VOL_2 is the exchange rate volatility measured using Equation (7). Please see the data sources section for detailed definitions of variables.

4.2. Panel Cointegration Tests

The first step in our econometric research was to see if any of the variables in Equation (1) have panel unit-roots. Even though the panel unit-root tests were performed, the results of these tests were not provided in order to keep the paper's length to a minimum. We then used Pedroni's Heterogeneous Panel Cointegration Test to see if the variables in Equation (1) are co-integrated, and the results are reported in Table 2. For each of the five countries, the results indicate evidence of cointegration among the four variables. The panel v-statistic is a one-sided test, with large positive values rejecting the null hypothesis of no cointegration and high negative values rejecting the null hypothesis of no cointegration for the remaining six test statistics. With a maximum lag of 12, the number of lag lengths was automatically selected based on SIC criterion. Regardless of which exchange rate volatility measure was used, all seven test statistics are statistically significant at the 1%, 5%, or 10% level of significance. Since there is strong evidence of cointegration among the four variables, we decided not to carry out additional tests of panel cointegration. Thus, Pedroni's Heterogeneous Panel Cointegration Test show clear evidence of cointegration among four variables for each country, regardless of which measure of exchange rate volatility is used.

Table 2. Pedroni's Heterogeneous Panel Cointegration Tests.

Panel A: Series: *lnREX, lnRER, lnY, lnVOL*$_1$					
Statistic	**Brazil**	**China**	**India**	**Russia**	**South Africa**
Panel	6.510 ***	3.295 ***	8.880 ***	3.641 ***	5.823 ***
ν-Statistic	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
Panel	−20.272 ***	−9.757 ***	−24.843 ***	−25.942 ***	−21.145 ***
ρ-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel	−15.132 ***	−11.902 ***	−18.163 ***	−19.064 ***	−16.235 ***
PP-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel	−12.194 ***	−6.661 ***	−15.825 ***	−11.770 ***	−10.286 ***
ADF-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	−20.793 ***	−6.624 ***	−20.791 ***	−23.490 ***	−26.988 ***
ρ-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	−17.715 ***	−9.842 ***	−17.110 ***	−19.265 ***	−20.406 ***
PP-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	−7.731 ***	−5.468***	−7.847 ***	−10.278 ***	−7.780 ***
ADF-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 2. *Cont.*

Panel B: Series: *lnREX, lnRER, lnY, lnVOL*$_2$					
Statistic	**Brazil**	**China**	**India**	**Russia**	**South Africa**
Panel	1.833 **	2.930 ***	8.517 ***	2.700 ***	3.374 ***
ν-Statistic	(0.033)	(0.002)	(0.000)	(0.004)	(0.000)
Panel	−8.627 ***	−8.997 ***	−25.265 ***	−24.414 ***	−20.177 ***
ρ-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel	−8.104 ***	−11.554 ***	−18.152 ***	−18.327 ***	−15.805 ***
PP-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel	−4.531 ***	−13.799 ***	−7.509 ***	−12.702 ***	−10.940 ***
ADF-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	−9.874 ***	−5.566 ***	−20.696 *	−21.667 ***	−25.630 ***
ρ-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	−9.221 ***	−9.913 ***	−16.956 ***	−18.021 ***	−19.808 ***
PP-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	−5.864 ***	−9.499 ***	−7.115 ***	−10.481 ***	−8.477 ***
ADF-Statistic	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: This table displays the results of the Pedroni's Heterogeneous Panel Cointegration Test. Of the seven tests, the panel v-statistic is a one-sided test, with large positive values rejecting the null hypothesis of no cointegration and high negative values rejecting the null hypothesis of no cointegration for the remaining six test statistics. With a maximum lag of 12, the number of lag lengths was automatically selected based on SIC criterion. The figures in the parentheses are p-values. The signs ***, **, and * indicate statistical significance of the test statistic at 1%, 5%, and 10% levels, respectively.

4.3. Analysis of Panel Regressions

After determining whether there is cointegration or a long-term association between the four variables, the next step is to estimate the panel regression models. We employed three estimating methods for this, namely, the Panel Least Squares, Panel Fully Modified Least Squares (FMOLS), and Panel Dynamic Least Squares (DOLS). The results of the panel regression models are presented in Tables 3 and 4. Table 3 shows the estimated results obtained under three estimation methods for each of the five countries when the first measure of volatility is used, while Table 4 shows similar results when the second measure of volatility is used.

Panel A of Table 3 presents the results obtained using the Panel Least Squares estimation method. Consistent with the model specified in Equation (1) and hypothesized sign, the coefficient for *RER* is negative in all countries but it is statistically significant at the 1% level for Brazil, China, and India. However, it is not statistically significant for Russia and South Africa. The coefficient of *Y* has the expected positive sign and is statistically significant at the 1% level in all countries except China, where it is significant at the 5% level. The coefficient for VOL_1, hypothesized to be either positive or negative, is positive and significant at the 1% level for Brazil, China, and India. The coefficient is negative and statically significant at the 1% level for Russia. However, it is positive and statistically insignificant for South Africa. The computed models' explanatory power is also quite strong, as evidenced from the Adjusted R^2 exceeding 0.75 in each model.

Panel B of Table 3 presents the results obtained using the Panel Fully Modified Least Squares estimation method. Similar to the results obtained under the Panel Least Squares, the coefficient for *RER* has the hypothesized negative sign in all countries, but it is statistically significant at the 1% level for Brazil, China, and India while it is not statistically significant for Russia or South Africa. The coefficient of *Y* has the expected positive sign and is statistically significant at the 1% level in all countries except China, where it is significant at the 10% level. The coefficient for VOL_1 is positive and significant at the 1% level for Brazil, China, and India. The coefficient is negative and statically significant at the 1% level for Russia. However, it is positive and statistically insignificant for South Africa. Similar to the results presented in Panel A, the explanatory powers of the estimated models are also very high, as evidenced from the Adjusted R^2 exceeding 0.75 in each model.

Table 3. Results of the Regressions with Volatility Measure VOL_1.

Panel A: Panel Least Squares					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
Constant	−9.9240 ***	−5.8556 ***	−9.8804 ***	−4.7429 ***	−6.4620 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnRER	−0.3389 ***	−0.8458 ***	−1.0383 ***	−0.0191	−0.0886
	(0.000)	(0.001)	(0.000)	(0.514)	(0.292)
lnY	2.0020 ***	2.6414 **	2.0481 ***	1.4427 ***	1.9597 ***
	(0.000)	(0.019)	(0.000)	(0.000)	(0.000)
$lnVOL_1$	0.1043 ***	0.2860 ***	0.0795 ***	−0.0672 ***	0.0870
	(0.000)	(0.000)	(0.000)	(0.000)	(0.360)
Industry FE	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	No	No	No
Adjusted R^2	0.8413	0.7662	0.8361	0.7526	0.8573
No of Obs.	2279	1800	2267	2261	2254
No of Products	20	20	20	20	20
Panel B: Panel Fully Modified Least Squares (FMOLS)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
lnRER	−0.3491 ***	−1.9815 ***	−0.8064 ***	−0.0382	−0.2371
	(0.001)	(0.000)	(0.003)	(0.433)	(0.112)
lnY	2.3393 ***	1.6340 *	2.2292 ***	1.5009 ***	2.3662 ***
	(0.000)	(0.076)	(0.000)	(0.000)	(0.000)
$lnVOL_1$	0.1114 ***	0.3368 ***	0.0928 ***	−0.0648 ***	0.0257
	(0.000)	(0.000)	(0.000)	(0.000)	(0.137)
Industry FE	No	No	No	No	No
Time FE	No	No	No	No	No
Adjusted R^2	0.8418	0.7657	0.8356	0.7528	0.8522
No of Obs.	2259	1780	2247	2244	2215
No of Products	20	20	20	20	20
Panel C: Panel Dynamic Least Squares (DOLS)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
lnRER	−0.1404 **	−1.3525 **	−0.7890 ***	−0.0254	−0.3323 *
	(0.029)	(0.012)	(0.006)	(0.652)	(0.058)
lnY	2.5299 ***	2.9472	2.3096 ***	1.6565 ***	2.5452 ***
	(0.000)	(0.455)	(0.000)	(0.000)	(0.000)
$lnVOL_1$	0.0915 **	0.3413 ***	0.0827 ***	−0.0453 **	0.0358 *
	(0.013)	(0.000)	(0.004)	(0.016)	(0.083)
Industry FE	No	No	No	No	No
Time FE	No	No	No	No	No
Adjusted R^2	0.8493	0.8241	0.8554	0.7845	0.8674
No of Obs.	2216	1740	2207	2205	2135
No of Products	20	20	20	20	20

Note: This table displays the estimated results of the model specified in Equation (1). The heteroskedastic-robust adjusted standard errors are in parentheses. Three estimating methods, i.e., the Panel Least Squares, Panel Fully Modified Least Squares, and Panel Dynamic Least Squares were employed to estimate Equation (1). The dependent variable is the logarithm of real exports, *lnREX*; *lnRER* is the logarithm of the real exchange rate as defined in Equation (4); *lnY* is the logarithm of the real income; and $lnVOL_1$ is the logarithm of volatility measure as defined in Equations (5) and (6). The sample period is from 1993Q1 to 2021Q2. The statistical significance of estimated coefficient at 1%, 5%, and 10% levels are indicated by signs ***, **, and *, respectively.

Panel C of Table 3 presents the results obtained using the Panel Dynamic Least Squares estimation method. Similar to the results obtained under the Panel Least Squares and Panel Modified Least Squares, the coefficient for *RER* has the hypothesized negative sign in all countries but it is statistically significant at the 1% level for India, at the 5% level for Brazil and China, and at the 10% level for South Africa, while it is not statistically significant for Russia. The coefficient of *Y* has the expected positive sign and is statistically significant at the 1% level in all countries except China. The coefficient for VOL_1 is positive

and significant at the 1% level for China and India and at the 5% level for Brazil. The coefficient is negative and statistically significant at the 1% level for Russia. It is positive and statistically significant at the 10% level for South Africa. Similar to the results presented in Panels A and B, the explanatory powers of the estimated models are also very high, as evidenced from the Adjusted R^2 exceeding 0.78 in each model.

Table 4. Results of the Regressions with Volatility Measure VOL_2.

Panel A: Panel Least Squares					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
Constant	2.1963 ***	−3.7850	−9.6254 ***	−6.1874 ***	−6.2321 ***
	(0.001)	(0.138)	(0.000)	(0.000)	(0.000)
lnRER	−0.6630 ***	−0.4764 ***	−1.4305 ***	−0.0434 *	−0.0366
	(0.000)	(0.000)	(0.000)	(0.085)	(0.312)
lnY	1.3004 **	2.6068 **	2.0526 ***	1.6785 ***	1.8909 ***
	(0.038)	(0.000)	(0.000)	(0.000)	(0.000)
$lnVOL_2$	1.2013	0.2778 ***	0.1256 ***	−0.0619 ***	−0.1509
	(0.111)	(0.000)	(0.000)	(0.000)	(0.800)
Industry FE	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	No	No	No
Adjusted R^2	0.8544	0.7499	0.8354	0.7465	0.8504
No of Obs.	2276	1797	2264	2258	2271
No of Products	20	20	20	20	20
Panel B: Panel Fully Modified Least Squares (FMOLS)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
lnRER	−0.2311 *	−1.5567 ***	−1.4559 ***	−0.0286	−0.1284
	(0.056)	(0.000)	(0.000)	(0.544)	(0.330)
lnY	2.2596 ***	1.6312 ***	2.0907 ***	1.8038 ***	2.0794 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$lnVOL_2$	0.4524	0.2974 ***	0.2196 ***	−0.0699 **	−0.2691
	(0.776)	(0.000)	(0.001)	(0.018)	(0.152)
Industry FE	No	No	No	No	No
Time FE	No	No	No	No	No
Adjusted R^2	0.8277	0.7541	0.8346	0.7462	0.8533
No of Obs.	2256	1777	2244	2241	2252
No of Products	20	20	20	20	20
Panel C: Panel Dynamic Least Squares (DOLS)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
lnRER	−0.1404 **	−1.6729 ***	−1.564 ***	−0.0198	−0.3237
	(0.029)	(0.000)	(0.006)	(0.763)	(0.558)
lnY	2.5299 ***	2.6473 ***	2.0154 ***	1.8783 ***	2.1930 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$lnVOL_2$	0.0415	0.3697 ***	0.2771 ***	−0.0430	−0.0832
	(0.130)	(0.000)	(0.003)	(0.125)	(0.161)
Industry FE	No	No	No	No	No
Time FE	No	No	No	No	No
Adjusted R^2	0.8493	0.8073	0.8529	0.7787	0.8676
No of Obs.	2216	1737	2204	2202	2212
No of Products	20	20	20	20	20

Note: This table displays the estimated results of the model specified in Equation (1). The heteroskedastic-robust adjusted standard errors are in parentheses. Three estimating methods, i.e., the Panel Least Squares, Panel Fully Modified Least Squares, and Panel Dynamic Least Squares were employed to estimate Equation (1). The dependent variable is the logarithm of real exports, *lnREX*; *LnRER* is the logarithm of the real exchange rate as defined in Equation (4); *lnY* is the logarithm of the real income; and $lnVOL_2$ is the logarithm of volatility measure as defined in Equation (7). The sample period is from 1993Q1 to 2021Q2. The statistical significance of estimated coefficient at 1%, 5%, and 10% levels are indicated by signs ***, **, and *, respectively.

Based on the results presented in Panels A, B, and C in Table 3, it can be concluded that both *RER* and *Y* variables have the expected signs regardless of which estimation method was used. The effect of exchange rate volatility of exports is positive for Brazil, China, India, and South Africa, while it is negative for Russia.

Table 4 shows the estimated results obtained under three estimation methods for each of the five countries when the second measure of volatility is used. Similar to the results presented in Table 3, the results obtained under three estimation methods are presented in Panels A, B, and C of Table 4.

Panel A of Table 4 presents the results obtained using the Panel Least Squares estimation method. Consistent with the model specified in Equation (1) and hypothesized sign, the coefficient for *RER* is negative in all countries, but it is statistically significant at the 1% level for Brazil, China, and India, and significant at the 10% level for Russia. However, it is not statistically significant for South Africa. The coefficient of *Y* has the expected positive sign and is statistically significant at the 1% level for India, Russia, and South Africa, while it is significant at the 5% level for Brazil and China.

The coefficient for VOL_2 is positive and significant at the 1% level for China and India and positive and not significant for Brazil. The coefficient is negative and statistically significant at the 1% level for Russia. However, it is negative and statistically insignificant for South Africa. The explanatory powers of the estimated models are also very high, as evidenced from the Adjusted R^2 exceeding 0.74 in each model.

Panel B of Table 4 presents the results obtained using the Panel Fully Modified Least Squares estimation method. Similar to the results obtained under the Panel Least Squares in Panel A, the coefficient for *RER* has the expected negative sign in all countries and it is statistically significant at the 1% level for China and India. The coefficient is significant at the 10% level for Brazil, but it is not statistically significant for Russia and South Africa. The coefficient of *Y* is statistically significant at the 1% level and has the expected positive sign and in all countries. The coefficient for VOL_2 is positive and significant at the 1% level for China and India. The coefficient is negative and statistically significant at the 5% level for Russia. However, it is positive and statistically insignificant for Brazil, and it is negative and statistically insignificant for South Africa. Similar to the results presented in Panel A, the computed models' explanatory powers are also quite good, as indicated by Adjusted R^2 values surpassing 0.75 in each model.

The results obtained using the Panel Dynamic Least Squares estimation method are presented in Panel C of Table 4. Similar to the results obtained under the Panel Least Squares and Panel Modified Least Squares, the coefficient for *RER* has the expected negative sign in all countries; it is statistically significant at the 1% level for China and India and at the 5% level for Brazil, but it is not statistically significant for Russia and South Africa. The coefficient of *Y* has the expected positive sign and statistically significant at the 1% level in all countries. The coefficient for VOL_2 is positive for Brazil, China, and India, and it is significant at the 1% level for China and India. The coefficient is negative and not statistically significant for Russia and South Africa. Similar to the results presented in Panels A and B, the computed models' explanatory powers are also quite good, as indicated by Adjusted R^2 values surpassing 0.77 in each model.

Based on the results shown in Table 4, it can be concluded that both *RER* and *Y* variables have the expected signs regardless of which estimation method was used. The effect of exchange rate volatility of exports is positive for Brazil, China, and India, while it is negative for Russia and South Africa.

4.4. Analysis of ARDL-Error-Correction Models

This section discusses the results of the error-correction models. Results of error-correction models when our first measure of volatility is used are presented in Table 5, and the equivalent results when the second measure of volatility is used are presented in Table 6. In Panel A of Table 5, we find that the long-run coefficients of *RER* and *Y* variables have the expected signs. The *RER* variable is statistically significant only for Brazil, India,

and South Africa. The Y variable is statistically significant at the 1% level in all cases. The sign of the VOL_1 variable is negative for Russia and positive for the other four countries. The coefficient is also statistically significant at the 1% or 5% level for Brazil, China, India, and Russia.

Table 5. Results of the ARDL-ECM with Volatility Measure VOL_1.

Panel A: Long-Run Equation (Dependent Variable: Δ*lnREX*)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
$lnRER_t$	−1.1465 *** (0.000)	−2.6088(0.424)	−1.9685 *** (0.000)	−0.6030 (0.412)	−1.9725 *** (0.000)
lnY_t	2.9722 *** (0.000)	2.5021 *** (0.003)	2.5825 *** (0.000)	1.6935 *** (0.009)	2.8256 *** (0.000)
$lnVOL_{1t}$	0.1208 *** (0.000)	0.2654 ** (0.000)	0.0996 *** (0.009)	−0.1094 *** (0.000)	0.1282 (0.281)
Panel B: Short-Run Equation (Dependent Variable: Δ*lnREX*)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
EC_{t-1}	−0.1238 *** (0.000)	−0.1084 *** (0.000)	−0.1254 *** (0.000)	−0.2261 *** (0.000)	−0.1220 *** (0.000)
$\Delta lnREX_{t-1}$	−0.3869 *** (0.000)	−0.3301 *** (0.000)	−0.4076 *** (0.000)	−0.3054 *** (0.000)	−0.4344 *** (0.000)
$\Delta lnREX_{t-2}$	−0.2532 *** (0.000)	−0.2752 ** (0.000)	−0.2870 *** (0.000)	−0.2057 *** (0.000)	−0.3269 *** (0.000)
$\Delta lnREX_{t-3}$	−0.0986 *** (0.000)	−0.2448 *** (0.000)	−0.1470 *** (0.000)	−0.0874 *** (0.000)	−0.1590 *** (0.000)
$\Delta lnRER_t$	−0.2945 ** (0.038)	−1.0220 (0.217)	−0.2926 (0.245)	−0.0980 *** (0.000)	−0.2331 (0.217)
$\Delta lnRER_{t-1}$	−0.1426 (0.127)	−1.1227 ** (0.013)		−0.0162 (0.372)	
$\Delta lnRER_{t-2}$	−0.1766 * (0.085)				
$\Delta lnRER_{t-3}$		−1.1419 (0.129)	−0.2504 (0.405)		−0.2129 (0.181)
ΔlnY_t	0.4338 * (0.063)	1.2578 *** (0.000)	0.4285 ** (0.044)	0.5873 ** (0.041)	0.4813 * (0.062)
ΔlnY_{t-1}	0.5596 *** (0.005)			0.4564 (0.149)	0.1609 (0.467)
ΔlnY_{t-2}			0.4104 (0.176)		
ΔlnY_{t-3}		0.6208 (0.217)	0.2387 * (0.069)		
$\Delta lnVOL_{1t}$	−0.0173 (0.329)		−0.0675 (0.102)		−0.1136 * (0.099)
$\Delta lnVOL_{1t-1}$		−0.0548 (0.301)	−0.0830 (0.193)	−0.0612 * (0.089)	−0.0102 (0.282)
$\Delta lnVOL_{1t-2}$	−0.0172 (0.468)			−0.0209 (0.271)	−0.0370 (0.468)
$\Delta lnVOL_{1t-3}$		−0.0778 (0.112)	−0.0586 (0.160)	−0.0262 (0.260)	
Constant	−1.1586 *** (0.000)	−2.2530 *** (0.000)	−0.8070 *** (0.000)	−0.2290 *** (0.005)	−1.9855 *** (0.000)
Log Likelihood	642.03	246.80	409.40	136.62	288.72
No of Obs.	2195	1720	2160	2166	2085
No of Products	20	20	20	20	20

Note: This table shows the regression results of the error-correction model specified in Equation (3). The signs ***, **, and * indicate statistical significance of t-statistic at 1%, 5%, and 10% levels, respectively. The dependent variable is the first difference of the logarithm of real exports, $\Delta lnREX$; EC_{t-1} is the error-correction term; *lnRER* is the logarithm of the real exchange rate as defined in Equation (4); *lnY* is the logarithm of the real income as proxied by the Industrial Production Index (2010 = 100); and $lnVOL_1$ is the logarithm of volatility measure as defined in Equations (5) and (6). The sample period is from 1993Q1 to 2021Q2.

Table 6. Results of the ARDL-ECM with Volatility Measure VOL_2.

Panel A: Long-Run Equation (Dependent Variable: Δ*lnREX*)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
$lnRER_t$	−1.6082 ***	−2.1920 ***	−1.5722 ***	−0.1732 **	−1.3816 ***
	(0.000)	(0.001)	(0.007)	(0.039)	(0.000)
lnY_t	1.1738 ***	2.3195 ***	2.8267 ***	1.6611 ***	2.7066 ***
	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)
$lnVOL_{2t}$	0.0862 **	0.0660	0.2686 *	−0.0532	0.1278
	(0.041)	(0.704)	(0.095)	(0.450)	(0.902)
Panel B: Short-Run Equation (Dependent Variable: Δ*lnREX*)					
Variable	**Brazil**	**China**	**India**	**Russia**	**South Africa**
EC_{t-1}	−0.1750 ***	−0.1897 ***	−0.1288 ***	−0.2140 ***	−0.1312 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta lnREX_{t-1}$	−0.4110 ***	−0.3554 ***	−0.4175 ***	−0.3180 ***	−0.4347 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta lnREX_{t-2}$	−0.2736 ***	−0.2890 **	−0.2895 ***	−0.2144 ***	−0.3165 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta lnREX_{t-3}$	−0.1098 ***	−0.2478 ***	−0.1469 ***	−0.0980 ***	−0.1562 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta lnRER_t$	−0.2462 **	−1.6992 **	−0.1501	−0.0915 *	−0.2618
	(0.012)	(0.014)	(0.224)	(0.082)	(0.202)
$\Delta lnRER_{t-1}$	−0.2222	−0.9645 **		−0.0521 *	
	(0.107)	(0.015)		(0.091)	
$\Delta lnRER_{t-2}$	−0.1870 **				
	(0.043)				
$\Delta lnRER_{t-3}$		−0.9252	−0.1851	−0.0424 **	−0.1148
		(0.216)	(0.469)	(0.038)	(0.301)
ΔlnY_t	0.8555 ***	1.1282 ***	0.4732 *	0.6726 *	0.2251 *
	(0.001)	(0.000)	(0.097)	(0.058)	(0.071)
ΔlnY_{t-1}	0.8260 ***			0.4809	0.1627
	(0.000)			(0.112)	(0.289)
ΔlnY_{t-2}			0.4102		
			(0.256)		
ΔlnY_{t-3}		0.6639	0.2304		
		(0.251)	(0.506)		
$\Delta lnVOL_{1t}$	−0.0114	−0.0918 **	−0.0574	−0.0752 *	−0.1129 *
	(0.224)	(0.028)	(0.537)	(0.068)	(0.093)
$\Delta lnVOL_{2t-1}$		−0.0625 **	−0.0430		−0.0173
		(0.016)	(0.223)		(0.161)
$\Delta lnVOL_{2t-2}$	−0.0368			−0.0592 ***	−0.0138
	(0.328)			(0.000)	(0.470)
$\Delta lnVOL_{2t-3}$			−0.0779 **	−0.0391	
			(0.011)	(0.184)	
Constant	−1.3655 ***	−2.9377 ***	−0.8306 ***	−0.6804 ***	−2.1949 ***
	(0.000)	(0.000)	(0.000)	(0.005)	(0.000)
Log Likelihood	625.34	218.60	310.20	124.40	212.75
No of Obs.	2192	1717	2157	2163	2082
No of Products	20	20	20	20	20

Note: This table shows the regression results of the error-correction model specified in Equation (3). The signs ***, **, and * indicate statistical significance of t-statistic at 1%, 5%, and 10% levels, respectively. The dependent variable is the first difference of the logarithm of real exports, $\Delta lnREX$; EC_{t-1} is the error-correction term; *lnRER* is the logarithm of the real exchange rate as defined in Equation (4); *lnY* is the logarithm of the real income as proxied by the Industrial Production Index (2010 = 100); and $lnVOL_2$ is the logarithm of volatility measure as defined in Equation (7). The sample period is from 1993Q1 to 2021Q2.

In Panel B of Table 5, the error-correction term is negative and statistically significant at the 1% level in all five countries. This also confirms the long-run cointegrating relationship between the four variables in all cases. Since our objective is to find the short-run effects of exchange rate volatility on exports, we are focusing only on the lagged values of the

volatility measure in Panel B. It is interesting to note that all coefficients of the lagged VOL_1 variable are negative in all five countries. However, one coefficient for Russia and one coefficient for South Africa are statistically significant at the 10% level, and all other coefficients are not statistically significant.

In Panel A of Table 6, we find that the long-run coefficients of *RER* and *Y* variables have the expected signs. The *RER* variable is statistically significant at the 1% or 5% level for all countries. The *Y* variable is statistically significant at the 1% level in all cases. Similar to the results found in Table 5, the sign of the VOL_2 variable is negative for Russia and positive for the other four countries. However, it is statistically significant only for Brazil and India.

In Panel B of Table 6, the error-correction term is negative and statistically significant at the 1% level in all five countries, similar to the results found in Panel B of Table 5. This also confirms the long-run cointegrating relationship between the four variables in all cases. As in in Table 5, we are focusing only on the lagged values of the volatility measure in Panel B. All coefficients of the lagged VOL_2 variable are negative in all five countries, as it was found in Table 5. When we use the second volatility measure, we find that more coefficients of the lagged volatility variable are statistically significant. We find statistically significant coefficients in four of the five countries. Thus, we can conclude that the short-run effect of exchange rate volatility on exports is negative in all five countries, regardless of which measure of volatility is used.

5. Summary and Conclusions

In this study, we used a multivariate error-correction model to investigate the dynamic link between exports and exchange rate volatility in BRICS nations. Using quarterly data from 1993Q1 to 2021Q2, estimates of long-run export demand functions were derived using the ARDL approach to cointegration.

Before estimating the specified models using the three estimation methods, we utilized the Pedroni's Heterogeneous Panel Cointegration Test to test for panel cointegration. Pedroni's Heterogeneous Panel Cointegration Test provides clear evidence of cointegration among four variables for each country, regardless of which measure of exchange rate volatility is used.

The model specified in Equation (1) was first estimated using three estimation methods, i.e., Panel Least Squares, Panel Fully Modified OLS and Panel Dynamic OLS. Results show that real exchange rate variable is significant for all countries, for all three estimation methods. Foreign income variable is also significant for all countries. The results also show that the estimated coefficient is positive and statistically significant in four of the five countries regardless of which measure of exchange rate volatility is used.

In all five nations, the cointegration results clearly reveal that a long-run equilibrium relationship exists between real exports, real foreign income, real exchange rate, and real exchange rate volatility. In the long term, all of the specifications produced expected coefficient signs. The majority of our computed coefficients are statistically significant at the 1% or 5% levels. There is also no significance variation of the exchange rate volatility on exports among countries in the short-run. All of the coefficients of the lagged exchange rate volatility variable are negative, though some of them are not statistically insignificant in the short-run. These results point to the increasing competitiveness of the United States when trading with BRICS as a result of the depreciating value of the local currency over time.

Effects of exchange rates on the trade flows among nations has become one of the long-standing objects of policy debate. It is a vital role of policy makers to be aware of the impact of exchange rate volatility on trade flows to achieve sustainable objectives in the long and short term. Further, establishing fluctuations in the exchange rate and determining the magnitude of the effects of volatility are important in focusing domestic policies. Such focus might assist in alleviating the impact of exchange rate volatility. The results of this paper are of great significance for policy makers on managing exchange rate volatility and preventing possible risks due to notable dependence among markets. Policy makers should

decide on the extent and timing of foreign exchange rate intervention. More generally, a country may exercise competitive devaluation to enhance export competitiveness for sustainable economic growth and development.

The restricted number of products included in the study is one of the study's drawbacks. While the current study only focused on the top 20 export products for each of the five BRICS countries, a larger coverage of products would have yielded more meaningful results. Future study will examine the effects of exchange rate volatility on each of the export products in each of the five nations.

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Appendix A

Table A1. Top 20 U.S. Export Products to BRICS in 2020.

Panel A: Top 20 U.S. Export Products to Brazil			
HS	**Product**	**Value of Exports (US $ Millions)**	**Export Share**
HS 27	Mineral Fuels, Mineral Oils and Products of Their Distillation	9075.6	26.0%
HS 84	Nuclear Reactors, Boilers, Machinery and Mechanical Appliances	3683.4	10.5%
HS 85	Electrical Machinery and Equipment and Parts Thereof	3131.7	9.0%
HS 39	Plastics and Articles Thereof	1893.8	5.4%
HS 29	Organic Chemicals	1682.8	4.8%
HS 38	Chemical Products N.E.C.	1551.5	4.4%
HS 90	Optical, Photographic, Cinematographic, Measuring, Checking, Medical or Surgical Instruments	1318.4	3.8%
HS 30	Pharmaceutical Products	1114.3	3.2%
HS 87	Vehicles; Other than Railway or Tramway Rolling Stock	804.6	2.3%
HS 28	Inorganic Chemicals; Organic and Inorganic Compounds of Precious Metals	659.8	1.9%
HS 22	Beverages, Spirits and Vinegar	352.4	1.0%
HS 40	Rubber and Articles Thereof	351.4	1.0%
HS 73	Iron or Steel Articles	242.0	0.7%
HS 10	Cereals	204.8	0.6%
HS 32	Tanning or Dyeing Extracts; Tannings and Their Derivatives; Dyes and Other Coloring Matter	147.7	0.4%
HS 48	Paper and Paperboard; Articles of Paper Pulp, of Paper or Paperboard	94.8	0.3%
HS 35	Albuminoidal Substances; Modified Starches; Glues; Enzymes	93.6	0.3%
HS 72	Iron and Steel	87.9	0.3%
HS 23	Food Industries, Residues and Wastes Thereof; Prepared Animal Fodder	62.9	0.2%
HS 82	Tools, Implements, Cutlery, Spoons and Forks, of Base Metal; Parts Thereof, of Base Metal	62.6	0.2%

Table A1. *Cont.*

	Total of Top 20 Products	**26,616.1**	**76.1%**
	Panel B: Top 20 U.S. Export Products to China		
HS	**Product**	**Value of Exports (US $ Millions)**	**Export Share**
HS 85	Electrical Machinery and Equipment and Parts Thereof	16,995.1	13.6%
HS 12	Oil Seeds and Oleaginous Fruits; Miscellaneous Grains, Seeds and Fruit, Industrial or Medicinal Plants	14,940.2	12.0%
HS 84	Nuclear Reactors, Boilers, Machinery and Mechanical Appliances	13,800.1	11.1%
HS 27	Mineral Fuels, Mineral Oils and Products of Their Distillation	9955.7	8.0%
HS 90	Optical, Photographic, Cinematographic, Measuring, Checking, Medical or Surgical Instruments	9507.3	7.6%
HS 87	Vehicles; Other than Railway or Tramway Rolling Stock	8177.1	6.6%
HS 39	Plastics and Articles Thereof	5412.7	4.3%
HS 30	Pharmaceutical Products	4616.7	3.7%
HS 02	Meat and Edible Meat Offal	3150.1	2.5%
HS 38	Chemical Products N.E.C.	2999.4	2.4%
HS 10	Cereals	2956.2	2.4%
HS 29	Organic Chemicals	2466.9	2.0%
HS 52	Cotton	1823.0	1.5%
HS 44	Wood and Articles of Wood; Wood Charcoal	1575.6	1.3%
HS 28	Inorganic Chemicals; Organic and Inorganic Compounds of Precious Metals	892.5	0.7%
HS 08	Fruit and Nuts, Edible; Peel of Citrus Fruit or Melons	839.0	0.7%
HS 48	Paper and Paperboard; Articles of Paper Pulp, of Paper or Paperboard	755.5	0.6%
HS 03	Fish and Crustaceans, Molluscs and Other Aquatic Invertebrates	696.8	0.6%
HS 26	Ores, Slag and Ash	643.5	0.5%
HS 73	Iron or Steel Articles	580.4	0.5%
	Total of Top 20 Products	**102,783.9**	**82.5%**
	Panel C: Top 20 U.S. Export Products to India		
HS	**Product**	**Value of Exports (US $ Millions)**	**Export Share**
HS 27	Mineral Fuels, Mineral Oils and Products of Their Distillation	6964.7	25.5%
HS 84	Nuclear Reactors, Boilers, Machinery and Mechanical Appliances	1943.5	7.1%
HS 29	Organic Chemicals	1679.4	6.1%
HS 85	Electrical Machinery and Equipment and Parts Thereof	1503.3	5.5%
HS 90	Optical, Photographic, Cinematographic, Measuring, Checking, Medical or Surgical Instruments	1162.3	4.3%
HS 08	Fruit and Nuts, Edible; Peel of Citrus Fruit or Melons	981.2	3.6%
HS 39	Plastics and Articles Thereof	896.3	3.3%
HS 38	Chemical Products N.E.C.	586.9	2.1%
HS 28	Inorganic Chemicals; Organic and Inorganic Compounds of Precious Metals	429.8	1.6%
HS 30	Pharmaceutical Products	404.0	1.5%
HS 72	Iron and Steel	381.2	1.4%
HS 87	Vehicles; Other than Railway or Tramway Rolling Stock	323.7	1.2%
HS 22	Beverages, Spirits and Vinegar	313.1	1.1%
HS 73	Iron or Steel Articles	156.6	0.6%
HS 52	Cotton	149.8	0.5%
HS 40	Rubber and Articles Thereof	146.8	0.5%
HS 48	Paper and Paperboard; Articles of Paper Pulp, of Paper or Paperboard	125.6	0.5%
HS 32	Tanning or Dyeing Extracts; Tannings and Their Derivatives; Dyes and Other Coloring Matter	87.8	0.3%

Table A1. *Cont.*

HS 93	Arms and Ammunition; Parts and Accessories Thereof	82.3	0.3%
HS 35	Albuminoidal Substances; Modified Starches; Glues; Enzymes	63.6	0.2%
	Total of Top 20 Products	**18,382.2**	**67.3%**
	Panel D: Top 20 U.S. Export Products to Russia		
HS	**Product**	**Value of Exports (US $ Millions)**	**Export Share**
HS 84	Nuclear Reactors, Boilers, Machinery and Mechanical Appliances	1087.4	22.3%
HS 87	Vehicles; Other than Railway or Tramway Rolling Stock	611.9	12.5%
HS 90	Optical, Photographic, Cinematographic, Measuring, Checking, Medical or Surgical Instruments	513.4	10.5%
HS 30	Pharmaceutical Products	391.8	8.0%
HS 85	Electrical Machinery and Equipment and Parts Thereof	386.9	7.9%
HS 39	Plastics and Articles Thereof	177.1	3.6%
HS 38	Chemical Products N.E.C.	166.8	3.4%
HS 40	Rubber and Articles Thereof	96.7	2.0%
HS 73	Iron or Steel Articles	55.2	1.1%
HS 21	Miscellaneous Edible Preparations	52.5	1.1%
HS 29	Organic Chemicals	42.9	0.9%
HS 24	Tobacco and Manufactured Tobacco Substitutes	30.9	0.6%
HS 12	Oil Seeds and Oleaginous Fruits; Miscellaneous Grains, Seeds and Fruit, Industrial or Medicinal Plants	25.2	0.5%
HS 28	Inorganic Chemicals; Organic and Inorganic Compounds of Precious Metals	24.3	0.5%
HS 82	Tools, Implements, Cutlery, Spoons and Forks, of Base Metal; Parts Thereof, of Base Metal	22.7	0.5%
HS 23	Food Industries, Residues and Wastes Thereof; Prepared Animal Fodder	19.9	0.4%
HS 05	Animal Originated Products; Not Elsewhere Specified or Included	18.2	0.4%
HS 27	Mineral Fuels, Mineral Oils and Products of Their Distillation	17.5	0.4%
HS 32	Tanning or Dyeing Extracts; Tannings and Their Derivatives; Dyes and Other Coloring Matter	15.4	0.3%
HS 35	Albuminoidal Substances; Modified Starches; Glues; Enzymes	14.8	0.3%
	Total of Top 20 Products	**3771.6**	**77.3%**
	Panel E: Top 20 U.S. Export Products to South Africa		
HS	**Product**	**Value of Exports (US $ Millions)**	**Export Share**
HS 84	Nuclear Reactors, Boilers, Machinery and Mechanical Appliances	754.8	17.0%
HS 87	Vehicles; Other than Railway or Tramway Rolling Stock	550.6	12.4%
HS 27	Mineral Fuels, Mineral Oils and Products of Their Distillation	514.2	11.5%
HS 85	Electrical Machinery and Equipment and Parts Thereof	285.8	6.4%
HS 90	Optical, Photographic, Cinematographic, Measuring, Checking, Medical or Surgical Instruments	242.6	5.4%
HS 38	Chemical Products N.E.C.	219.3	4.9%
HS 39	Plastics and Articles Thereof	208.0	4.7%
HS 30	Pharmaceutical Products	122.4	2.7%
HS 40	Rubber and Articles Thereof	91.8	2.1%
HS 02	Meat and Edible Meat Offal	77.5	1.7%
HS 29	Organic Chemicals	46.0	1.0%
HS 23	Food Industries, Residues and Wastes Thereof; Prepared Animal Fodder	39.1	0.9%
HS 48	Paper and Paperboard; Articles of Paper Pulp, of Paper or Paperboard	35.2	0.8%
HS 73	Iron or Steel Articles	34.4	0.8%
HS 12	Oil Seeds and Oleaginous Fruits; Miscellaneous Grains, Seeds and Fruit, Industrial or Medicinal Plants	33.7	0.8%

Table A1. *Cont.*

HS 28	Inorganic Chemicals; Organic and Inorganic Compounds of Precious Metals	32.2	0.7%
HS 35	Albuminoidal Substances; Modified Starches; Glues; Enzymes	30.6	0.7%
HS 21	Miscellaneous Edible Preparations	30.2	0.7%
HS 10	Cereals	29.7	0.7%
HS 82	Tools, Implements, Cutlery, Spoons and Forks, of Base Metal; Parts Thereof, of Base Metal	23.0	0.5%
	Total of Top 20 Products	**3401.2**	**76.4%**

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