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The asymmetric effects of exchange rate volatility on US–Pakistan trade flows: new evidence from nonlinear ARDL approach

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Abstract
Earlier studies that examined the response of trade flows to exchange rate volatility relied on the assumption that increased volatility and decreased volatility behave in a symmetric way; however, due to change in expectations of traders toward increasing volatility and decreasing volatility, the effects could be asymmetric; hence, the empirical results of these studies are supposed to have masked by the restricted assumption of symmetry between exchange rate and trade flows. This study investigates both the symmetric and asymmetric effects of exchange rate volatility on trade flows between Pakistan and USA at industry level over the period 1981–2018. We find evidence of a significant effect of asymmetric exchange rate volatility on trade flows in almost one-half (1/2) of importing and exporting industries of Pakistan that trade with the USA both in the short run and in the long run.

Keywords Asymmetric effects · Exchange rate volatility · Commodity trade · Pakistan · USA · Nonlinear ARDL

1 Introduction

Since the collapse of the fixed exchange rate system in 1973, the real exchange rate and the nominal exchange rate have become more volatile. A number of studies have investigated the link between exchange rate uncertainty and trade flows from both

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theoretical and empirical perspectives. There is a consensus between both groups that uncertainty in the exchange rate measured as exchange rate volatility may affect trade flows both positively and negatively. According to De Grauwe (1988), the trader's response to the volatility of the exchange rate is impingent upon investors' attitude toward risk. An investor with risk-averse behavior is likely to respond by avoiding trade in the face of exchange rate uncertainty, while risk-lover investors may respond by enhancing economic activities to avoid future income loss. Thus, the dominance of the trader's risk-lover and risk-averse behavior matters that may eventually decide that how is exchange rate volatility likely to affect trade flows.

To find evidence in support of the theory, the empirical studies conducted so far followed three distinct paths. The first strand of the study pertains to one country and the rest of the world, while relying on aggregate-level trade data. While these studies have been criticized since they embody an aggregation bias, therefore, many other studies have examined the impact of exchange rate uncertainty on trade flows at the bilateral level. However, many of these studies have ended up showing mixed results; more importantly, the results are supposed to be country-specific. Also, the findings of these studies have been criticized with a view that they tend to suffer from second aggregation bias; hence, many studies have moved toward industry-/commodity-level analysis while investigating the nexus between exchange rate volatility and the trade flows (e.g., Bahmani-Oskooee et al. 2017a). Yet, the number of industries responding to exchange rate volatility tends to vary from country to country.

This study focuses on Pakistan and the USA to investigate the response of uncertainty in the exchange rate on commodity trade flows between both of the countries. In terms of Pakistan's exports to the rest of the world, the USA is Pakistan's largest export destination with 16% of exports of Pakistan being directed to the USA and they amounted to $3869 million in FY 2018, while during the same period, Pakistan's imports from the USA amounted to $2077 million, indicating that Pakistan has significant trade relations with the USA if compared by the total exports of Pakistan to the world which amounted $ 23.6 billion during the same period. Besides, the USA is among the top investors in Pakistan over the past two decades. Major investment is concentrated in "consumer goods, chemicals, energy, agriculture, business process outsourcing, transportation, and communications". In recent years, some economic reforms have been made by the country which has helped in providing a conducing environment for the investors which is evidenced by the fact that Pakistan has shown improvement in its rankings of World Bank's Ease of Doing Business in 2019. However, at the same time, given the product mix of Pakistan's exports, it has to face strong competition from countries such as China, India, Vietnam and Bangladesh. These countries have experienced a significant increase in exports, in particular, in textile to the USA, while those exports from Pakistan have remained stagnant over the past few years. Thus, an empirical investigation of Pakistan–US trade is important to be investigated in the context of exchange rate dynamics.

Since the present study investigates the impact of exchange rate volatility on commodity-level trade flows of Pakistan and the USA, we present an overview of empirical studies related to Pakistan. As far as the empirical literature on exchange rate volatility and trade flows is concerned, in the case of Pakistan, there are several studies in this regard that can be divided into three directions, i.e., the studies relying on aggregate, bilateral and industry-/commoditywise trade data. Aggregate-level studies include the study of Kumar and Dhawan (1991) who examined the impact of exchange rate volatility on Pakistan's exports to the developed countries; Similarly, Bahmani-Oskooee and Payesteh (1993) examined the impact of exchange rate volatility on trade flows that included Pakistan; Doganlar (2002) examined the impact of exchange rate volatility on trade flows in five Asian countries including Pakistan; Genc and Artar (2014) examined the impact for emerging economies including Pakistan; and Lotfalipour and Bazargan (2014), Bahmani-Oskooee and Ltaifa (1992), Sauer and Bohara (2001), Khan et al. (2014) included Pakistan in their sample and found mixed results. Similarly, other studies that used the aggregate-level trade data while exploring the nexus between the exchange rate volatility and the trade flows included Javed and Farooq (2009); Alam (2010); Mahmood et al. (2011); Khan et al. (2014); and Humayon et al. (2014).

Since that, these studies have relied on aggregate-level trade data; hence, the empirical results of these studies have been criticized because of the aggregation bias that these studies tend to embody. Hence, many studies have switched to using bilateral-level trade data between Pakistan against her trading partner which includes the study of Mustafa and Nishat (2004), Aurangzeb et al. (2005), Alam and Ahamd (2011), Hassan (2013) and Alam et al. (2017). However, the results of these studies were also mixed at large. Hence, to account for another bias, Bahmani-Oskooee et al. (2016, 2017b) studied in detail the impact of exchange rate volatility on commodity-level trade flows between Pakistan and the USA, Pakistan and Japan as well. In the US case, the results show that 50% of the industries of Pakistan were affected by the exchange rate volatility in the short run; however, the significant short-run effect lasted into the long run only in a limited number of industries. All these studies in the case of Pakistan have assumed that exchange rate volatility has a symmetric effect on trade flows, i.e., the variable of exchange rate volatility has a single elasticity coefficient indicating that both positive volatility and negative volatility tend to affect the trade flows in a similar way. However, recent studies by Bahmani-Oskooee and Aftab (2017), Fedoseeva (2016), Bahmani-Oskooee and Mohammadian (2016), Bahmani-Oskooee and Arize (2020) and Aye and Harris (2019) find out significant evidence in favor of asymmetric effects of exchange rate on trade flows. These studies rejected the idea that exchange rate volatility may affect trade flows in a symmetric way; rather, they suggested that both appreciation and depreciation may affect trade flows in an asymmetric way. Hence, this study is an attempt to fill this gap and examine the impact of exchange rate volatility on Pakistan–US commodity trade flows while assuming both symmetric and asymmetric approaches to cointegration.

The rest of the study is organized as below: Sect. 2 presents an empirical model and methods and Sect. 3 presents empirical results, while Sect. 4 concludes.

2 Empirical model and methods

Earlier studies that estimated the effect of exchange rate volatility on trade flows have mostly incorporated a scale variable such as real income, a relative price term measured by the real exchange rate and a degree of exchange rate uncertainty created as volatility of the real exchange rate (Bahmani-Oskooee and Hegerty 2007; Bahmani-Oskooee and Harvey 2011; Bahmani-Oskooee et al. 2013). We hypothesize that imports and exports of a country depend upon the volatility of the exchange rate along with other variables such as exchange rate and economic activity. Hence, we use the following standard form for the model:

$$\mathrm{Ln}X^{\mathrm{Pak}} = \alpha_0 + \alpha_1 \mathrm{LnIP}_t^{\mathrm{US}} + \alpha_2 \mathrm{LnREX}_t + \alpha_3 \,\mathrm{Ln}V_t + \varepsilon_t \tag{1}$$

$$\mathrm{Ln}M^{\mathrm{Pak}} = \beta_0 + \beta_1 \mathrm{LnIP}_t^{\mathrm{Pak}} + \beta_2 \mathrm{LnREX}_t + \beta_3 \mathrm{Ln}V_t + \mu_t \tag{2}$$

where X^{Pak} and M^{Pak} are real exports of Pakistan to the USA and real imports from the USA, respectively. $\mathrm{IP}_t^{\mathrm{US}}$ is the industrial production index of the USA, and $\mathrm{IP}_t^{\mathrm{Pak}}$ is the industrial production index of Pakistan. Both variables $\mathrm{IP}_t^{\mathrm{US}}$ and $\mathrm{IP}_t^{\mathrm{Pak}}$ are used to represent economic activities. Thus, an increase in $\mathrm{IP}_t^{\mathrm{US}}$ and $\mathrm{IP}_t^{\mathrm{Pak}}$ indicates an increase in income of the USA and Pakistan, respectively. An increase in the US income may likely have a positive impact on exports of Pakistan, while an increase in Pakistan's economic activities represented by the industrial production index is expected to boost up Pakistan's imports from the USA. Thus, α_1 and β_1 are supposed to carry positive signs, respectively. REX_t is the real bilateral exchange rate, which is considered in a way that an increase reflects a depreciation of the Pakistani rupee or appreciation of the dollar. If depreciation of the rupee increases the exports of Pakistan, then there is an expectation that there will be a decrease in imports from the USA; thus, we anticipate α_2 and β_2 to be positive and negative, respectively. V_t is the volatility of the exchange rate. Exchange rate volatility can affect trade in both ways, positively and negatively; hence, α_3 and β_3 can be positive and negative as well.

The next step is to check out the long-run and short-run impact of exchange rate uncertainty on trade by using Eqs. 1 and 2. Hence, we separate the short-run impact from the long run by using the ARDL bound testing approach used by Pesaran et al. (2001) and identify Eqs. 1 and 2 as an error correction model:

$$\Delta Lnx_{i,t}^{pak} = c_1 + \sum_{j=1}^{n1} c_2 \Delta Lnx_{t-j}^{pak} + \sum_{j=0}^{n2} c_{3j} \Delta LnIP_{t-j}^{us} + \sum_{j=0}^{n3} c_{4j}\, \Delta LnRex_{t-j} + \sum_{j=0}^{n4} c_{5j}\, \Delta LnV_{t-1} + \theta_1 Lnx_{t-1}^{pak} + \theta_2 LNIP_{t-1}^{us} + \theta_3 LnRex_{t-1} + \theta_4 LnV_{t-1} + \varepsilon_t \tag{3}$$

The impart function can be written as follows:

$$\Delta \text{Ln}M_{i,t}^{\text{pak}} = d_1 + \sum_{j=1}^{n5} d_2 \Delta \text{Ln}M_{t-j}^{\text{pak}} + \sum_{j=0}^{n6} d_{3j} \Delta \text{LnIP}_{t-j}^{\text{pak}} + \sum_{j=0}^{n7} d_{4j} \Delta \text{LnRex}_{t-j} + \sum_{j=0}^{n8} d_{5j} \Delta \text{Ln}V_{t-j} + \delta_1 \text{Ln}M_{i,t}^{\text{pak}} + \delta_2 \text{LnIP}_{t-1}^{\text{pak}} + \delta_3 \text{LnRex}_{t-1} + \delta_4 \text{Ln}V_{t-1} + \exists_t \quad (4)$$

In Eq. 3, the summation symbols indicate the error correction dynamics, while the second portion of the equation shows the long-run relationship among the variables. Similarly, γ_1 is drift and ç is the error term. Thus, we use ARDL bound test approach to estimate Eq. 3 by OLS. The F test is used to check the existence of cointegration. The null hypothesis for bound test, i.e., H_0: $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 0$, indicates no cointegration, whereas alternative hypothesis is that H_1: $\theta_1 \neq 0$, $\theta_2 \neq 0$, $\theta_3 \neq 0$, $\theta_4 \neq 0$. Equation 3 is our export demand model. Equation 4 is our import demand model. The null hypothesis for bound test in Eq. 4 is H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$, and alternative hypothesis is H_1: $\delta_1 \neq 0, \delta_2 \neq 0$, $\delta_3 \neq 0, \delta_4 \neq 0$. If the cointegration exists, we move to error correction representation; thus, we can estimate error correction model through the following equations:

$$\Delta \text{Ln}x_{i,t}^{\text{pak}} = e_1 + \sum_{j=1}^{n1} e_2 \Delta \text{Ln}x_{t-j}^{\text{pak}} + \sum_{j=0}^{n2} e_{3j} \Delta \text{LnIP}_{t-j}^{\text{us}} + \sum_{j=0}^{n3} e_{4j} \Delta \text{LnRex}_{t-j} + \sum_{j=0}^{n4} e_{5j} \Delta \text{Ln}V_{t-1} + \tau \text{ECM}_{t-1} + \xi_t \quad (5)$$

And for the import function, we use the following equation:

$$\Delta \text{Ln}M_{i,t}^{\text{pak}} = f_1 + \sum_{j=1}^{n5} f_{2j} \Delta \text{Ln}M_{t-j}^{\text{pak}} + \sum_{j=0}^{n6} f_{3j} \Delta \text{LnIP}_{t-j}^{\text{pak}} + \sum_{j=0}^{n7} f_{4j} \Delta \text{LnRex}_{t-j} + \sum_{j=0}^{n8} f_{5j} \Delta \text{Ln}V_{t-j} + \vartheta \text{ECM}_{t-1} + v_t \quad (6)$$

In the above models, we estimate the symmetric effects of exchange rate volatility on the imports and exports of Pakistan. In many previous studies, the symmetric effects of exchange rate volatility are analyzed. But this may not be true, because increased volatility may affect trade flows differently than decreased volatility (Bahmani-Oskooee and Mohammadian 2016; Bahmani-Oskooee and Aftab 2017). To deal with the limitation inherent in the symmetric approach to cointegration, we follow the approach applied by Granger and Yoon (2002), Hatemi-J (2012, 2014). This approach investigates the “hidden cointegration” between the components of the series. It is helpful in the sense that it may allow checking for the evidence of long-run cointegration between the positive and negative subcomponents of a series even though there may not be any linear cointegration between the aggregate-level series. In other words, the asymmetric approach is preferable in the sense that it not only allows to examine the response of trade flows to changes in exchange rate volatility; rather, it shows the impact of positive and negative shocks separately on trade flows. According to Granger and Yoon (2002), Hatemi-J (2014), Hatemi-J and El-Khatib

(2014, 2016), "the non-linear adjustment mechanism to long-run equilibrium can be easily reduced to a linear one without any loss of information." Both the data series are supposed to have hidden cointegration if both positive and negative series are cointegrated. This type of nonlinear cointegration is important to be examined in particular, when the ordinary linear cointegration approach is unable to identify this hidden cointegrating relationship. To check the asymmetric effects of exchange rate uncertainty, we generate positive POS_t and negative NEG_t variables from the volatility. POS_t variable indicates the increased volatility as the partial sum of positive variations. On the other hand, the NEG_t variable indicates decreased volatility. This type of nonlinear cointegration is important to be examined in particular, when the ordinary linear cointegration approach is unable to identify this hidden cointegrating relationship. For instance, if there are two random walk series Z_t and Y_t

$$Z_t = Z_{t-1} + \mu_t = z_0 + \sum_{t=1}^{t} \mu_i \tag{7}$$

$$Y_t = Y_{t-1} + \Gamma_t = Y_0 + \sum_{t=1}^{t} \_i \tag{8}$$

where $t=1, 2, \ldots, T$ and Z_0, Y_0 are initial values, μ_i and I_i denote mean zero white noise disturbance terms. "If the two series, i.e., Y_t and Z_t, are cointegrated by one vector, they are deemed to have a standard or linear cointegration. However, if both series tend to move in an asymmetric way, then the two series are expected to have the possibility of a hidden cointegration. According to Granger and Yoon (2002), both positive and negative shocks can be defined in the following way:

$$\begin{aligned} &\mu_i^+ = \max(\mu_i, 0), \mu_i^- = \min(\mu_i, 0), {}'I_i^+ = \max({}'I_i, 0), {}'I_i^- = \min({}'I_i, 0), \\ &\mu_i = \mu_i^+ + \mu_i^- \text{ and } {}'I_i = {}'I_i^+ + {}'I_i^- \end{aligned} \tag{9}$$

Hence,

$$Z_t = Z_{t-1} + \mu_t = z_0 + \sum_{t=1}^{t} \mu_i^+ + \sum_{t=1}^{t} \mu_i^- \text{ and } Y_t = Y_{t-1} + {}'I_t = Y_0 + \sum_{t=1}^{t} {}'I_i^+ + \sum_{t=1}^{t} {}'I_i^- \tag{10}$$

To simplify the notations,

$$Z_i^+ = \sum_{t=1}^{t} \mu_i^+, Z_i^- = \sum_{t=1}^{t} \mu_i^-, Y_i^+ = \sum_{t=1}^{t} {}'I_i^+, Y_i^- = \sum_{t=1}^{t} {}'I_i^- \tag{11}$$

Thus,

$$Z_t = z_0 + Z_i^+ + Z_i^- \text{ and } Y_t = y_0 + Y_i^+ + Y_i^- \tag{12}$$

$$\Delta Z_t^+ = \mu_t^+, \Delta Z_t^- = \mu_t^-, \Delta Y_t^+ = {}'I_t^+, \Delta Y_t^- = {}'I_t^-$$

subsequently. To obtain the series of both positive and negative movements, i.e., ΔZ_t^+ and ΔZ_t^-, we calculate the first difference of the series as $\Delta Z_t = Z_t - Z_{t-1}$. Finally, both these positive and negative values are transformed into a cumulative sum of positive (negative) changes as $Z_t^+ = \sum \Delta Z_t^+$ and $Z_t^- = \sum \Delta Z_t^-$. The same procedure is pursued for the other series as follows: $Y_t^+ = \sum \Delta Y_t^+$ and $Y_t^- = \sum \Delta Y_t^-$. The hidden cointegration is supposed to exist between the series Z and Y if their components are cointegrated. Finally, for the sake of simplicity, we replace the series Z_t with our actual independent variable, i.e., the volatility of exchange rate, while Z_t^+ and Z_t^- are replaced with notations POS and NEG, respectively. Both POS and NEG are the appreciation and depreciation of the Pakistani rupee as shown below:

$$\mathrm{POS}t = \sum_{j=1}^{t} \Delta \ln Vj^{+} = \sum_{j=1}^{t} \max(\Delta \ln Vj, 0)$$

$$\mathrm{NEG}t = \sum_{j=1}^{t} \Delta \ln Vj^{-} = \sum_{j=1}^{t} \min(\Delta \ln Vj, 0)$$

Now our next model is a nonlinear model in which we interchange $\mathrm{Ln}V_t$ with POS_t and NEG_t variables. So our model is as follows:

$$\begin{aligned}\Delta \mathrm{Ln}x_{i,t}^{\mathrm{pak}} = g_1 &+ \sum_{j=1}^{n1} g_{2j}\Delta \mathrm{Ln}x_{t-j}^{\mathrm{pak}} + \sum_{j=0}^{n2} g_{3j}\Delta \mathrm{LnIP}_{t-j}^{\mathrm{us}} + \sum_{j=0}^{n3} g_{4j}\Delta \mathrm{LnREX}_{t-j} + \sum_{j=0}^{n4} g_{5j}\Delta \mathrm{POS}_{t-j} \\ &+ \sum_{j=0}^{n5} g_{6j}\mathrm{NEG}_{t-j} + \rho_1 \mathrm{Ln}x_{t-1}^{\mathrm{pak}} + \rho_2 \mathrm{LnIP}_{t-1}^{\mathrm{us}} \\ &+ \rho_3 \mathrm{LnREX}_{t-1} + \rho_4 \mathrm{POS}_{t-1} + \rho_5 \mathrm{NEG}_{t-1} + \Omega_t\end{aligned} \tag{13}$$

However, the equation using the imports as a dependent variable can be written as below:

$$\begin{aligned}\Delta \mathrm{Ln}M_{i,t}^{\mathrm{pak}} = h_1 &+ \sum_{j=1}^{n6} h_{2j}\Delta \mathrm{Ln}M_{t-j}^{\mathrm{pak}} + \sum_{j=0}^{n7} h_{3j}\Delta \mathrm{LnIP}_{t-j}^{\mathrm{pak}} + \sum_{j=0}^{n8} h_{4j}\Delta \mathrm{LnRe}x_{t-j} \\ &+ \sum_{j=0}^{n9} h_{5j}\Delta \mathrm{POS}_{t-j} + \sum_{j=0}^{n10} h_{6j}\mathrm{NEG}_{t-j} + \mu_1 \mathrm{Ln}M_{i,t}^{\mathrm{pak}} + \mu_2 \mathrm{LnIP}_{t-1}^{\mathrm{pak}} \\ &+ \mu_3 \mathrm{LnRe}x_{t-1} + \mu_4 \mathrm{POS}_{t-1} + \mu_5 \mathrm{NEG}_{t-1} + \varkappa_t\end{aligned} \tag{14}$$

According to Shin et al. (2014), Eqs. 13 and 14 are nonlinear ARDL models. For the construction of nonlinear ARDL, we separate the positive and negative variables by using a partial sum approach. Again, we estimated the ECM for asymmetric effects of exchange rate volatility. The ECM model for nonlinear ARDL is as follows:

$$\Delta \mathrm{Ln}x_{i,t}^{\mathrm{pak}} = j_1 + \sum_{j=1}^{n1} j_{2j}\Delta \mathrm{Ln}x_{t-j}^{\mathrm{pak}} + \sum_{j=0}^{n2} j_{3j}\Delta \mathrm{LnIP}_{t-j}^{us} + \sum_{j=0}^{n3} j_{4j}\Delta \mathrm{LnREX}_{t-j} + \sum_{j=0}^{n4} j_{5j}\Delta \mathrm{POS}_{t-j} + \sum_{j=0}^{n5} j_{6j}\mathrm{NEG}_{t-j} + \tau \mathrm{ECM}_{t-1} + \varpi_t \tag{15}$$

For import function, it is used as below:

$$\Delta \mathrm{Ln}M_{i,t}^{\mathrm{pak}} = k_1 + \sum_{j=1}^{n6} k_{2j}\Delta \mathrm{Ln}M_{t-j}^{\mathrm{pak}} + \sum_{j=0}^{n7} k_{3j}\Delta \mathrm{LnIP}_{t-j}^{\mathrm{pak}} + \sum_{j=0}^{n8} k_{4j}\Delta \mathrm{LnRex}_{t-j} + \sum_{j=0}^{n9} k_{5j}\Delta \mathrm{POS}_{t-j} + \sum_{j=0}^{n10} k_{6j}\mathrm{NEG}_{t-j} + \pi \mathrm{ECM}_{t-1} + \varrho_t \tag{16}$$

As per time-series studies, if we use nonstationary data or nonstationary variables for estimation, then our results will be spurious. To avoid this problem, we use different techniques to make our variables stationary. But the use of stationary variables provides short-run information from the data and eliminates the long-run information. Hence, there must be a technique through which one can compute whether there exists a long-run relationship among variables or not.

Most studies adopt Engle and Granger (1987) and Johansen and Juselius (1990) for cointegration or long-run analysis; however, to apply these approaches, variables must be integrated of the same order. The above-mentioned models are not suitable for small datasets. ARDL model incorporates all the problems of these tests. In the case of ARDL, we can use mixed variables that are stationary at level, $I(0)$ or stationary at $I(1)$ first difference (Pesaran et al. 2001).

ARDL test has many desirable properties. One of them is that we can check the long-run relationship or existence of cointegration without the concern that the series is stationary at the level or first difference. ARDL also incorporates the problem of endogeneity, since the focused variables need not be exogenous. This approach is best for both small and large samples. The first step of the ARDL approach is the bound test; the bound test is used to calculate the long-run relationship among the variables, by using the F test, with two sets upper and lower. The critical region is given in the form of lower bound $I(0)$ and upper bound $I(1)$ given by Pesaran et al. (2001). If the value of F.STAT exceeds the upper bound, then the null hypothesis of no cointegration is rejected. If the value of F.STAT is smaller than the lower bound, it means no existence of cointegration or no long-run relationship. On the other hand, if the value of F.STAT lies between the upper and lower bound, then the result will be inconclusive.

For the selection of the lag length model, we can use SBC and AIC criteria. The SBC is renowned as a parsimonious model, which selects minimum lag length, whereas AIC is identified for the selection of maximum lags. The second step is an estimation of the long-run relationship using ARDL based on AIC and SBC. If the model shows a long-run relationship between the variables, then there is error correction representation. If the value of ECM is negative and significant, it leads to a long-run relationship among the variables. It also justifies the speed of adjustment of divergence from the preceding year. To confirm the robustness of the results, stability tests are used. For the stability of the model, CUSUM and CUSUMSQ techniques introduced by Brown et al. (1975) are used in this study. If the plots of the data lie between the upper and lower bounds at the 5 percent level of significance, it means that our model is structurally stable and vice versa. We also apply the Wald test for the long-run and short-run results to test for the joint significance of variables.

The main focus of the study is on the asymmetric effects of exchange rate volatility on the imports and exports between Pakistan and the USA, while, for comparison, we also estimate the symmetric effects of exchange rate volatility. We also apply nonlinear ARDL by replacing the variable $\mathrm{Ln}V_t$ (volatility) with POS and NEG variable. For nonlinearity, we generate POS and NEG variables by using the partial sum concept (Shin et al. 2014). According to Pesaran et al. (2001), the bound test is the same for linear and nonlinear ARDL; we should handle both variables (POS & NEG) as one variable and use the same critical value of F.STAT as for $\mathrm{Ln}V_t$ in linear ARDL. Hence, we apply the bound test for Eqs. 13 and 14, while for the estimation of the error correction model, we use Eqs. 15 and 16 of import demand and export demand. We apply Wald-S for short symmetry and Wald-L for long symmetry in the nonlinear model.

3 Empirical results

Although our objective is to find out asymmetric effects of exchange rate volatility on trade flows by using nonlinear ARDL for Eqs. 13 and 14, to make our findings more clear and authentic, we also estimate linear ARDL for Eqs. 1 and 2. For this purpose, we include 48 industries of Pakistan that import from the USA and 22 industries that export to Pakistan. We first concentrate on the results of the linear model and estimate the import demand model (13) as above in Table 1. We mention the long-run results of the import demand model only to save time and therefore did not show the short-run results but assure the readers that there was at least one significant short-run coefficient attached to our measure of volatility. In Table 2, we indicate the long-run coefficients of the linear import demand model. There are 48 importing industries in Pakistan, which are importing different products from the USA. There are 29 industries out of 48 where one or more coefficient is significant.

There are seven importing industries out of 13 which are significantly but negatively affected by exchange rate volatility. These industries are coded as 11, 26, 52, 65, 73, 82 and 84. Imports of six industries are positively affected by exchange rate volatility. The major importing industry coded as 64 (with 34% import share) is positively affected by exchange rate volatility. And second industry (which has comparatively less share than the previous industry) coded as 65 (15%) is negatively affected by volatility. There are 19 industries in which the real exchange rate has a significant impact on their imports. There are 13 importing industries (25, 28, 33, 34, 41, 56, 57, 63, 64, 68, 72, 83 and 86) out of 19, in which the effect of the real exchange rate is negative and significant.

Table 1 Long-run estimates of linear ARDL import demand model

SITC	Industry	Share	LnV_t	Lnex	Lnipp	Constant
5	Fruit and vegetable	2.2998	– 7.34	27.38	– 211.24	– 15.56
6	Sugar, sugar preparations and honey	0.0997	– 1.42	0.53**	– 1.05	– 0.88*
9	Miscellaneous food preparations	0.1702	0.000	– 1.76	3.19	1.56
11	Beverages	0.0043	– 2.36*	– 0.45	3.96	– 8.01*
12	Tobacco and tobacco manufactures	0.000	0.97	2.01	– 8.77	35.61*
21	Hides, skins and fur skins, undress	0.0069	3.82	– 15.25	16.25	1.24
22	Oil seeds, oil nuts and oil kernels	3.5045	3.01**	– 4.26	1.94	17.94*
23	Crude rubber including synthetic an	0.084	– 0.66	1.38	1.23	– 3.24**
24	Wood, lumber and cork	1.3292	1.14	– 3.71	9.77**	– 17.7*
25	Pulp and paper	0.6817	0.27	– 2.19*	2.52*	9.11*
26	Textile fibers, not manufactured, a	5.512	– 1.26*	3.48*	– 0.94	1.83*
27	Crude fertilizers and crude mineral	0.1608	– 0.59	1.56	– 0.19	3.12*
28	Metalliferous ores and metal scrap	4.9188	0.42	– 10.66*	15.48*	– 12.20*
29	Crude animal and vegetable material	0.1915	0.04	0.62	0.53	4.23
32	Coal, coke and briquettes	0.0001	1.13	– 4.95	4.75	3.39
33	Petroleum and petroleum products	0.2465	0.36	– 3.01**	4.18*	2.89
34	Gas, natural and manufactured	0.0421	1.04*	– 6.07*	9.38*	– 15.9*
41	Animal oils and fats	0.0003	1.86	– 11.48*	10.10**	11.39
42	Fixed vegetable oils and fats	0.2659	– 0.74	– 0.53	0.47	9.55*
43	Animal and vegetable oils and fats,	0.004	– 0.69	– 1.22	4.69	– 10.75
51	Chemical elements and compounds	0.6728	0.1	0.17	– 0.93	14.83*
52	Crude chemicals from coal, petroleum	0.0006	– 8.99*	15.19**	– 8.52	– 23.64*
53	Dyeing, tanning and coloring mater	0.1339	– 0.14	0.34	0.66	3.86*
54	Medicinal and pharmaceutical products	0.9547	– 0.05	– 0.23	0.81*	7.85*
55	Perfume materials, toilet and cleansi	0.5188	– 0.34	1.26	0.91	0.63
56	Fertilizers, manufactured	0.0306	2.53	– 32.51*	31.54*	7.5
57	Explosives and pyrotechnic products	0.0618	0.34*	– 0.87*	5.81*	3.04*
58	Plastic materials, etc.	0.9338	– 0.21	– 0.95	2.01**	5.08*
59	Chemical materials and products	1.1902	0.55*	0.33**	0.52	3.21
61	Leather, lthr. Manufs., n.e.s & dre	0.1016	0.41	– 3.33	3.35	3.41
62	Rubber manufactures, n.e.s	0.1042	0.04	– 2.72	– 0.79**	2.47
63	Wood and cork manufactures excluding	0.0959	0.11	– 2.72*	5.35*	– 4.25*
64	Paper, paperboard and manufactures	0.3715	0.37**	– 1.19*	0.49*	3.63*
65	Textile yarn, fabrics, made up arti	0.1537	– 0.84**	1.45	0.62	– 0.47
66	Nonmetallic mineral manufactures,	0.1073	– 0.4	0.46	– 0.15	6.85*
67	Iron and steel	0.6101	– 0.74	1.36	– 0.49	7.4
68	Nonferrous metals	0.0363	– 0.22	– 2.60**	4.11*	0.26
69	Manufactures of metal, n.e.s	0.3418	– 2.16	3.77	– 2.1	5.05*
71	Machinery, other than electric	7.3861	0.57**	0.81	0.37	7.01
72	Electrical machinery and apparatus	2.959	– 0.06	– 1.62*	2.78*	5.99*
73	Transport equipment	4.2956	– 1.60*	2.66**	– 1.02	0.52*
81	Sanitary, plumbing, heating and lig	0.0337	0.15	– 0.24	0.73	0.36*

Table 1 (continued)

SITC	Industry	Share	LnV_t	Lnex	Lnipp	Constant
82	Furniture	0.0475	– 0.54*	0.24**	3.21	0.51
83	Travel goods, handbags and similar	0.0086	0.63	– 0.15*	0.75*	– 3.54*
84	Clothing	0.0713	– 0.91*	– 1.15	3.35*	– 1.82*
86	Scientif & control instrum, photogr	1.8958	– 0.19	– 0.23*	2.89*	4.69*
89	Miscellaneous manufactured articles	1.0422	0.25	– 1.25	2.74*	2.84*
93	Special transact. Not class. Accord	4.0659	– 0.03	0.41	1.38	4.18*

*Significance at 5%; **significance at 10%

In most models, the value of F.STAT is significant, thus supporting the idea of a long-run relationship among the variables. We also estimate the error correction model which explains the speed of adjustment toward equilibrium. The significantly negative value of ECM is supporting the existence of cointegration. The error correction model is the additional support to test the long-run relationship. In Table 2, we also report the value of R square. In maximum models, the value of R square is higher which is showing higher variation as explained by explanatory variables.

We also report LM (Lagrange multiplier) and Ramsey's RESET estimates. Both are estimated as Chi-square with one degree of freedom. LM is used to check the existence of autocorrelation. In most of the models, the value of LM is insignificant showing the absence of autocorrelation. To check the stability of the model, we have estimated CUSUM and CUSUM SQ. "S" is used to indicate stable, and "US" is used for the unstable model. Next in Table 3, we show the results of the linear export demand model. In Table 3, 22 exporting industries of Pakistan export their products to the USA. Exchange rate volatility has a positive and significant impact on three exporting industries (6, 21 and 63) out of eight industries.

There are five industries (9, 26, 81, 85 and 93), which are adversely affected by exchange rate volatility. The exchange rate has an adverse impact on the three largest exporting industries of Pakistan, coded as 81 (sanitary, plumbing, heating and lig with 26% export share), 26 (textile fibers, not manufactured with 43% export share) and 93 (special transact. Not class. According to 50% export share).

In Table 4, we present the estimated results of linear export demand. We have taken 22 exporting industries that are exporting different products to the USA. The value of F.STAT is significant in ten industries, thus supporting the existence of cointegration. The presence of a long-run relationship has been confirmed through ECM. The estimated value of LM is insignificant in maximum models indicating that the export demand model is properly specified and residuals are free from autocorrelation. For the stability of models, we have estimated the CUSUM and CUSUM sq.

In the next table, we consider the important contribution of the study which is the estimation of nonlinear import demand and export demand model. Hence, we first estimated the nonlinear ARDL for import demand. Short-run results for positive and negative changes are presented in Table 5. In Table 5, there are 25 importing industries in which increased volatility has a significant impact at one or more than one

Table 2 Diagnostic statistics associated with Table 1 (linear import demand model)

SITC	Industry	F.STAT	ECM	*R* sq	LM	RESET	CU	CU.Q
5	Fruit and vegetable	2.43	– 0.16 (0.90)	0.96	0.7356	1.57	S	S
6	Sugar, sugar preparations and honey	6.58*	– 0.72 (3.93)**	0.92	0.6535	0.11	S	S
9	Miscellaneous food preparations	2.76	– 0.28 (2.13)**	0.73	0.9999	0.23	US	S
11	Beverages	8.34*	– 0.90 (4.42)**	0.85	0.7422	1.55	S	S
12	Tobacco and tobacco manufactures	2.99	– 0.91 (2.88)**	0.88	0.8144	3.56	S	US
21	Hides, skins and fur skins, undress	2.63	– 0.36 (1.47)	0.56	0.1082	9.93	S	US
22	Oil seeds, oil nuts, and oil kernels	5.78*	– 1.41 (4.42)**	0.47	0.4886	0.42	S	S
23	Crude rubber including synthetic an	4.53*	– 0.68 (3.32)**	0.91	0.5875	0.07	S	US
24	Wood, lumber and cork	2.88	– 0.56 (2.10)**	0.93	0.4284	17.65	S	S
25	Pulp and paper	6.43*	– 0.66 (4.98)**	0.88	0.4709	0.38	S	S
26	Textile fibers, not manufactured, a	13.42*	– 1.07 (5.96)**	0.94	0.2563	0.65	S	S
27	Crude fertilizers and crude mineral	4.95*	– 0.54 (2.98)**	0.88	0.7153	1.35	S	US
28	Metalliferous ores and metal scrap	2.43	– 023 (2.77)**	0.89	0.4752	4.51	S	S
29	Crude animal and vegetable material	1.44	– 0.39 (1.54)	0.93	0.5551	0.43	S	US
32	Coal, coke and briquettes	1.06	– 0.34 (1.92) *	0.41	0.9713	2.17	S	S
33	Petroleum and petroleum products	4.37*	– 0.64 (3.92) *	0.34	0.9788	0.34	S	S
34	Gas, natural and manufactured	2.76	– 2.10 (4.83)**	0.66	0.0441	0.88	S	S
41	Animal oils and fats	7.50*	– 0.97 (5.35)**	0.24	0.5114	0.25	S	S
42	Fixed vegetable oils and fats	3.42	– 0.62 (3.47)**	0.33	0.3624	1.67	US	US
43	Animal and vegetable oils and fats,	4.83*	– 0.78 (4.52**	0.37	0.4571	0.55	S	US
51	Chemical elements and compounds	5.44*	– 0.51 (3.86)**	0.65	0.7077	0.78	S	S
52	Crude chemicals from coal, petroleum	6.14*	– 1.14 (4.78)**	0.48	0.5255	6.62	S	S
53	Dyeing, tanning and coloring mater	3.84**	– 0.82 (4.03)**	0.78	0.1441	1.82	S	S
54	Medicinal and pharmaceutical products	8.74*	– 2.60 (5.33)**	0.91	0.6101	1.58	S	S
55	Perfume materials, toilet and cleansi	2.81	– 0.33 (2.47)**	0.98	0.0888	0.55	S	S
56	Fertilizers, manufactured	6.63*	– 0.53 (4.00)**	0.85	0.2599	3.49	S	S
57	Explosives and pyrotechnic products	6.34*	– 2.28 (4.97)**	0.65	0.2427	0.17	S	S

Table 2 (continued)

SITC	Industry	F.STAT	ECM	R sq	LM	RESET	CU	CU.Q
58	Plastic materials, etc.	5.09*	– 0.64 (4.09)**	0.81	0.5541	0.45	S	US
59	Chemical materials and products	2.74	– 0.14 (0.75)	0.79	0.18	1.8	S	S
61	Leather, lthr. Manufs., n.e.s & dre	2.74	– 0.68 (2.99)**	0.6	0.1848	5.89	S	US
62	Rubber manufactures, n.e.s	2.27	– 0.47 (2.89)**	0.47	0.6603	0.07	S	US
63	Wood and cork manufactures excluding	6.94*	– 1.00 (5.27)**	0.83	0.3698	0.08	S	US
64	Paper, paperboard and manufactures	9.02*	– 2.38 (5.95)**	0.93	0.3563	1.48	S	S
65	Textile yarn, fabrics, made up arti	7.57*	– 1.01 (2.98)**	0.96	0.6517	0.63	S	S
66	Nonmetallic mineral manufactures,	2.24	– 0.92 (2.47)**	0.74	0.1089	0.95	S	S
67	Iron and steel	7.18*	– 0.97 (3.05)**	0.91	0.4891	0.03	S	US
68	Nonferrous metals	5.36*	– 0.75 (4.09)**	0.83	0.0255	0.01	S	S
69	Manufactures of metal, n.e.s	4.76*	– 0.52 (2.84)**	0.84	0.2764	2.37	S	US
71	Machinery, other than electric	9.73*	– 0.97 (5.25)**	0.87	0.0345	0.19	S	S
72	Electrical machinery and apparatus	2.1	– 0.81 (4.03)**	0.72	0.4379	3.44	S	S
73	Transport equipment	7.35*	– 1.04 (5.57)**	0.63	0.0175	1.07	S	S
81	Sanitary, plumbing, heating and lig	3.43	0.59 (3.51)**	0.33	0.8004	1.77	S	US
82	Furniture	4.57*	– 1.22 (3.06)**	0.67	0.5243	0.29	S	S
83	Travel goods, handbags and similar	12.61*	– 1.30 (7.71)**	0.59	0.0126	0.68	S	US
84	Clothing	6.56*	– 2.60 (4.72)**	0.87	0.2303	2.52	S	S
86	Scientif & control instrum, photogr	5.96*	– 0.80 (3.04)**	0.98	0.7448	0.88	S	S
89	Miscellaneous manufactured articles	2.28	– 0.56 (2.20)**	0.93	0.3933	1.35	S	S
93	Special transact. Not class. Accord	5.61*	– 1.44 (4.34)**	0.94	0.5741	2.32	S	S

n.e.s not elsewhere specified. The critical values for upper and lower bounds for 5% and 10% are 3.23 to 4.35 and 2.72 and 3.77, respectively. LM is Lagrange multiplier test of residual serial correlation. It is Chi-square distributed with one degree of freedom. Ramsey RESET test for functional form. It is also Chi-square distributed with one degree of freedom. Its critical value at 5% (1%) significance is 3.84 (6.63). Number inside the parenthesis is next to the coefficients which are the absolute values of *t*-ratios

*Significance at 5% and **significance at 10%

lag in the short run. Negative sign shows the adverse effect of increased volatility on importing industries coded as 6, 12, 22, 23, 29, 43, 61, 64, 68, 73, 83, 89, and 93.

On the other hand, 24 importing industries are significantly affected by the decreased volatility in the short run and this share is higher than the linear model. Thus, the separation of positive volatility from negative volatility is more useful.

Table 3 Long-run coefficients of linear export demand model

SITC	Industry	Share	LnV_t	Lnex	Lnipus	Constant
5	"Fruit and vegetables"	0.0717	0.17	0.26	– 0.39	9.43
6	"Sugar, sugar preparations and honey"	0.4616	0.81*	1.24	2.73	3.01
9	"Miscellaneous food preparations"	0.0558	– 0.44*	0.41	0.22*	– 3.18*
21	"Hides, skins and fur skins, undress"	0.0004	0.35*	0.97*	0.22*	– 3.57
26	"Textile fibers, not manufactured"	0.4321	– 0.81*	3.45*	– 2.67*	0.13
29	"Crude animal and vegetable material"	0.005	– 5.73	– 6.35	3.32	5.08
54	"Medicinal and pharmaceutical products"	0.0029	0.02	– 0.8	3.19	– 5.93
55	"Perfume materials, toilet & cleansi"	0.0133	– 0.11	1.99	1.31	– 8.67
61	"Leather, lthr. Manufs., n.e.s & dre"	0.1003	– 2.21	4.51	– 9.24	3.09
63	"Wood and cork manufactures excludin"	0.0052	0.39*	0.48	– 0.03	3.98
65	"Textile yarn, fabrics, made up arti"	19.8345	0.05	– 0.42	0.82*	– 6.36*
67	"Iron and steel"	0.2154	0.06	0.63	8.82	3.29
69	"Manufactures of metal, n.e.s"	0.4354	0.03	0.23	1.8	0.84
71	"Machinery, other than electric"	0.0502	– 0.05	1.2	1.86	– 3.17
72	"Electrical machinery and apparatus"	0.048	1.02	– 0.95	– 0.31	7.8
73	"Transport equipment"	0.0464	– 0.23	– 2.2	0.10*	3.71*
81	"Sanitary, plumbing, heating and lig"	0.2617	– 0.71*	0.47*	0.18*	1.22
82	"Furniture"	0.772	– 0.33	1.10*	– 0.3	– 3.91*
85	"Footwear"	0.0717	– 0.23*	3.08*	– 3.55*	1.45
86	"Scientif & control instrum, photogr"	1.3334	0.17	0.26	– 0.32	1.17
89	"Miscellaneous manufactured articles"	1.6323	– 0.81	0.79	2.43	– 3.51
93	"Special transact. Not class. Accord"	0.5049	– 0.9**	1.70**	– 1.58	9.62

*Significance at 5%; **significance at 10%

Through the nonlinear model, we can easily check the impacts of increased and decreased volatility separately on trade flows. There are 16 importing industries out of 24 importing industries that are adversely affected by decreased volatility since with negative volatility, traders may prefer to import less from the USA. Industries coded as 42 and 54 being with higher import share, i.e., 26% and 95%, respectively, are adversely affected by negative volatility. The asymmetric effects show that both increased volatility and decreased volatility have both types (significantly positive and significantly negative) of impact on importing industries of Pakistan. In other words, the asymmetric effects show that there is evidence of significant effects of increased volatility and decreased volatility on importing industries.

Table 6 indicates long-run estimates of the nonlinear ARDL model. In long run, imports of eight industries were affected by increased volatility. Among these industries, four industries (26, 27, 43 and 81) were negatively affected by the increased volatility. Increased volatility also has an adverse impact on two industries (43 and 81) in the short run. Decreased volatility has a significant and negative impact on four industries (23, 26, 27 and 67) and a positive impact on industries coded as (43, 52, 54, 83, 84, and 93).

Table 4 Diagnostic statistics associated with import demand models in Table 3

SITC	Industry	F.STAT	ECM	*R* sq	LM	RESET	CU	CU.Q
5	Fruit and vegetables	3.01	– 0.51 (2.71)**	0.71	0.9412	2.48	S	S
6	Sugar, sugar preparations and honey	10.29*	– 1.84 (6.40)**	0.92	0.4322	3.45	S	S
9	Miscellaneous food preparations	8.25*	– 1.34 (5.33)**	0.98	0.0768	0.19	S	US
21	Hides, skins and fur skins, undress	3.27	– 1.51 (3.49)**	0.82	0.0268	0.01	S	S
26	Textile fibers, not manufactured	5.44*	– 0.85 (4.52)**	0.93	0.2614	1.91	S	US
29	Crude animal and vegetable material	5.18*	0.18 (0.68)	0.92	0.0102	0.042	S	S
54	Medicinal and pharmaceutical products	3.67	– 0.54 (3.490**	0.98	0.9758	2.8	S	S
55	Perfume materials & toilet	2.16	– 0.52 (2.60)**	0.36	0.01	0.36	S	US
61	Leather, lthr. Manufs., n.e.s	4.68*	– 0.16 (1.70)	0.81	0.1674	0.01	S	S
63	Wood and cork manufactures excluding	8.91*	– 1.02 (4.85)**	0.91	0.1593	3.71	S	S
65	Textile yarn, fabrics, made up arti	3.98**	– 0.40 (– 3.08)**	0.93	0.7626	9.6	S	S
67	Iron and steel	4.34**	– 0.63 (3.80)**	0.99	0.93	2.29	S	S
69	Manufactures of metal, n.e.s	2.69	– 0.33 (3.98)**	0.43	0.5134	3.31	S	US
71	Machinery, other than electric	4.77*	– 0.77 (4.22)**	0.98	0.7204	13.59	US	US
72	Electrical machinery & apparatus	2.15	– 0.36 (2.64)**	0.75	0.8655	4.05	U	US
73	Transport equipment	6.22*	– 0.54 (4.38)**	0.54	0.5643	3.65	US	US
81	Sanitary, plumbing & heating	3.43	– 1.58 (3.79)**	0.88	0.6097	2.27	US	S
82	Furniture	5.81*	– 0.91 (4.60)**	0.96	0.4963	0.61	S	S
85	Footwear	2.67	– 0.68 (2.92)**	0.98	0.2759	0.21	S	S
86	Scientif & control instrum, photogr	0.79	– 0.12 (1.14)	0.94	0.882	1.88	S	S
89	Miscellaneous manufactured articles	6.10*	– 0.17 (2.35)**	0.92	1279	1.29	S	US
93	Special transact. Not class. Accord	2.32	– 0.50 (3.24)**	0.97	0.1689	1.6	S	S

n.e.s not elsewhere specified. The critical values for upper and lower bounds for 5% and 10% are 3.23–4.35 and 2.72 and 3.77, respectively. LM is Lagrange multiplier test of residual serial correlation. It is Chi-square distributed with one degree of freedom. Ramsey RESET test for functional form. It is also Chi-square distributed with one degree of freedom. Its critical values at 5% (1%) significance is 3.84 (6.63). Number inside the parenthesis is next to the coefficients which are the absolute values of *t* ratios

*Significance at 5%; **significance at 10%

In the long run, decreased volatility has a positive impact on the industry coded as 67 with an import share of 61 but it has no impact in the short run. Increased volatility and decreased volatility have a positive impact on the

Table 5 Short-run estimates attached to the POS and NEG variables nonlinear import model

SITC	Industry	Share	ΔPOS	ΔPOS_{t-1}	ΔPOS_{t-2}	ΔPOS_{t-3}	ΔNEG	ΔNEG_{t1}	ΔNEG_{t2}	ΔNEG_{t3}
5	"Fruit and vegetables"	2.2998	− 1.27*	0.61	1.31**	− 0.49	− 0.62	1.15	0.68	0.35
6	"Sugar, sugar preparations and honey"	0.0997	− 0.72	− 1.02*			0.04			
9	"Miscellaneous food preparations"	0.1702	− 0.07				0.03			
11	"Beverages"	0.0043	− 0.73	1.96**	0.13	1.12*	− 0.22	0.77	2.07*	
12	"Tobacco and tobacco manufactures"	0.000	0.77	0.99	− 2.97*	− 1.16**	1.1			
21	"Hides, skins and fur skins, undress"	0.0069	− 0.68				0.44			
22	"Oil seeds, oil nuts and oil kernels"	3.5045	1.4	− 2.98**			1.28	− 4.72*		
23	"Crude rubber including synthetic"	0.084	0.2	0.34	− 0.13	− 0.37*	− 0.13	0.54**		
24	"Wood, lumber and cork"	1.3292	0.16				0.01	− 1.06*	1.05*	
25	"Pulp and paper"	0.6817	− 0.45	0.01	0.08	0.3	0.25			
26	"Textile fibers, not manufactured"	5.512	0.44	0.44*	0.27**	0.27*	− 0.22**	0.67*		
27	"Crude fertilizers and crude mineral"	0.1608	− 0.24	0.39	0.72*	0.15	− 0.1	0.03	0.67*	0.67*
28	"Metalliferous ores and metal scrap"	4.9188	− 0.38				0.30*			
29	"Crude animal and vegetable material"	0.1915	− 0.05	− 0.50**	0.1	− 0.16	0.28*	− 0.13	− 0.52	0.15
32	"Coal, coke and briquettes"	0.0001	0.000				0.59			
33	"Petroleum and petroleum products"	0.2465	1.07*				− 0.02			
34	"Gas, natural and manufactured"	0.0421	− 0.46				2.21*	2.07*		
41	"Animal oils and fats"	0.0003	− 1.21	− 0.1	4.40		2.7	− 1.06	− 0.49	7.39**
42	"Fixed vegetable oils and fats"	0.2659	− 0.27				0.33	− 1.25*		
43	"Animal and vegetable oils and fats"	0.004	− 2.45**				1.87**			
51	"Chemical elements and compounds"	0.6728	2.7	− 1.02	− 1.48	0.28	− 0.12	− 2.43	− 1.39	1.9652
52	"Crude chemicals from coal, petroleum"	0.0006	3.14	6.42*	1.7		2.14	1.6	3.9	
53	"Dyeing, tanning and coloring mater"	0.1339	0.11				− 0.1			
54	"Medicinal and pharmaceutical prod"	0.9547	0.02	− 0.49	− 0.17	0.11	0.02	− 0.41*	− 0.63*	0.14

Table 5 (continued)

SITC	Industry	Share	ΔPOS	ΔPOS_{t-1}	ΔPOS_{t-2}	ΔPOS_{t-3}	ΔNEG	ΔNEG_{t1}	ΔNEG_{t2}	ΔNEG_{t3}
55	"Perfume materials and toilet"	0.5188	0.20*				0.04			
56	"Fertilizers, manufactured"	0.0306	1.55	− 0.14	− 1.7	− 2.26*	− 0.61			
57	"Explosives and pyrotechnic products"	0.0618	0.69**				0.25			
58	"Plastic materials, etc."	0.9338	0.05				− 0.04			
59	"Chemical materials and products"	1.1902	0.08				0.007			
61	"Leather, lthr. Manufs., n.e.s"	0.1016	− 0.57	− 0.86**	0.36	− 0.61*	− 0.51*	0.67	− 0.74	− 0.72*
62	"Rubber manufactures, n.e.s"	0.1042	− 0.03				0.23			
63	"Wood and cork manufactures excluding"	0.0959	0.23				0.07			
64	"Paper, paperboard and manufactures"	0.3715	− 0.27	− 0.01	− 0.53**	0.4	0.26	0.53		
65	"Textile yarn, fabrics, made up arti"	0.1537	− 0.003	0.22	0.31**		− 0.01	− 0.48*		
66	"Nonmetallic mineral manufactures"	0.1073	− 0.06	0.37			− 0.14	0.25	0.58*	− 0.28**
67	"Iron and steel"	0.6101	0.11				0.11**	023*		
68	"Nonferrous metals"	0.0363	− 1.00**	0.73	1.16		− 0.3	− 0.12	1.28**	0.83
69	"Manufactures of metal, n.e.s"	0.3418	0.04				− 0.01			
71	"Machinery, other than electric"	7.3861	− 0.1				0.09	0.11	0.11	0.13**
72	"Electrical machinery and apparatus"	2.959	0.3	− 0.34	− 0.35	0.47*	0.13	− 0.06	0.11	− 0.65**
73	"Transport equipment"	4.2956	− 0.32	− 1.26*	0.71*		0.32	0.52	− 1.29**	
81	"Sanitary, plumbing, heating and lig"	0.0337	0.28	− 0.28	0.42	− 0.73*	0.09			
82	"Furniture"	0.0475	− 0.09				0.11			
83	"Travel goods, handbags and similar"	0.0086	0.17	− 1.82*	− 0.74	− 0.68	0.47	− 1.18	− 1.74**	
84	"Clothing"	0.0713	0.25				0.06	− 0.01	− 0.67*	− 0.96*
86	"Scientif and control instrum"	1.8958	− 0.07	0.12	0.16	0.09	0.14*	0.171	− 0.06	0.17
89	"Miscellaneous manufactured articles"	1.0422	− 0.25**	− 0.11	0.07	− 0.13**	− 0.01			
93	"Special transact. Not class. Accord"	4.0659	0.44	− 0.89**	− 0.22	0.31	0.27	− 0.44	− 1.18**	

*Significance at 5%; **significance at 10%

importing industry (coded as 54 with 95% import share). It indicates that imports increase in both cases, i.e., with increasing as well as decreasing volatility

In the end, we move to the diagnostics in Table 7 which are related to the long-run estimates of the nonlinear import demand model (9). As we have mentioned in the above discussion, positive volatility and negative volatility have a different impact on imports. To confirm it further, we have used the Wald test for the short and the long run. Wald tests for short run and the long run were used to check whether increased volatility is equal to decreased volatility or the impact is asymmetric (Bahmani-Oskooee and Aftab 2017). Wald-S shows the short-run results, and Wald-L shows long-run results. There are 14 importing industries in which short-run and 12 industries in which long-run asymmetric effects of E.R. volatility exist. The insignificant values of LM indicate that the residuals are free from the autocorrelation. We have estimated CUSUM and CUSUM square for the stability of the model to make sure that our model is structurally stable.

In Table 8, we report the short-run results of the nonlinear export demand model. We represent the asymmetric impact of exchange rate volatility by using increased and decreased volatility. Increased volatility has a significant impact on the ten exporting industries. There are seven exporting industries (6, 54, 61, 63, 82, 86, and 89), which are negatively affected by increased volatility. It includes two exporting industries (6 and 82) which have a larger export share, but are negatively affected by increased volatility.

Decreased volatility has affected 14 industries. Out of these 14 industries, eight industries (6, 21, 63, 65, 69, 89, 9, 93) are negatively affected by decreased volatility. It includes manufactures of metal, n.e.s, coded as 69 which have a share of 43%. The exporting industry (sugar, sugar preparations and honey with code 6) is negatively affected by the decreased volatility. Both increased volatility and decreased volatility hurt the exports of this industry. The largest exporting industry 26 (textile fibers, not manufactured with 43% export share) is positively affected by the increased volatility; on the other hand, decreased volatility also has a positive impact on the export of this industry. In the case of the textile industry, the income effect holds because traders enhance their trade activities and did not reduce export. In this way, they can compensate for their future loss. Our next table indicates the long-run results of nonlinear export demand mode.

Table 9 shows the long-run impact of increased and decreased volatility on the exports of Pakistan to the USA. Increased volatility has a significantly negative impact on four industries coded as 63, 73, 82 and 9. Decreased volatility has a significantly negative impact on four industries which are coded as 26, 81, 82 and 9. Two major exporting industries, i.e., 26 and 81, were affected by decreased volatility. It shows that depreciation in currency causes a decline in exports of these industries. Increased volatility and decreased volatility have the same impact (positive) on the exporting industry [sugar, sugar preparations, and honey (9)] in the long run. In the end, for the validity of long-run estimates, we established cointegration among the variables. We also estimated ECM for more accurate results. The values of LM show that our models are free from the problem of autocorrelation. For comparison between asymmetric and symmetric effects, we have established the Wald test for long- and short-run results. In the case of exporting industries, in a total

Table 6 Long-run results of nonlinear ARDL import demand model

SITC	Industry	Share	Lnipp	Lnex	Pos	Neg	Constant
11	"Beverages"	0.0043	– 0.95	3.02	– 10.79	– 8.62	309.8
12	"Tobacco and tobacco manufactures"	0.000	– 1.23	– 2.64	20.26	4.246	– 206.84
21	"Hides, skins and fur skins, undress"	0.0069	– 3.96	– 7.89	8.61	– 20.13	425.09
22	"Oil seeds, oil nuts and oil kernels"	3.5045	– 0.47	– 6.65	4.63	4.22	– 125.58
23	"Crude rubber including synthetic"	0.084	0.75	– 0.37*	0.09	– 0.58**	7.21
24	"Wood, lumber and cork"	1.3292	3.22	– 8.42	0.28	– 1.02	3.97
25	"Pulp and paper"	0.6817	3.98**	9.1	– 1.15	0.43	19.54**
26	"Textile fibers, not manufactured"	5.512	– 0.56*	0.44*	– 1.08*	– 1.04*	– 37.11*
27	"Crude fertilizers and crude mineral"	0.1608	– 3.77	– 0.52*	– 2.47*	– 2.46*	90.00*
28	"Metalliferous ores and metal scrap"	4.9188	26.7	5.9	– 3.01	– 0.25	11.87
29	"Crude animal and vegetable material"	0.1915	3.23*	0.74	0.13	0.44	– 8.72
32	"Coal, coke and briquettes"	0.0001	8.32	6.06	0.009	1.65	– 36.32
33	"Petroleum and petroleum products"	0.2465	0.122	– 6.87*	0.80*	– 0.02	– 2.21
34	"Gas, natural and manufactured"	0.0421	6.66*	– 3.06	– 0.26	– 0.22	– 0.26
41	"Animal oils and fats"	0.0003	6.91	15.33	– 7.78	– 5.37	220.93
42	"Fixed vegetable oils and fats"	0.2659	6.94	7.26	– 0.42	1.19	– 16.16
43	"Animal and vegetable oils and fats"	0.004	14.8*	7.75*	– 1.24**	0.92*	– 18.03
5	"Fruit and vegetables"	2.2998	21.51	0.05	4.3	6.66	– 198.7
51	"Chemical elements and compounds"	0.6728	4.68	– 1.5	2.54	3.04	– 86.42
52	"Crude chemicals from coal, petroleum"	0.0006	14.71	12.81	9.32*	10.27*	317.93*
53	"Dyeing, tanning and coloring mater"	0.1339	– 0.22	– 1.5	0.15	– 0.13	5.88
54	"Medicinal and pharmaceutical production"	0.9547	1.46*	– 0.03	0.14*	0.24*	0.16
55	"Perfume materials and toilet"	0.5188	1.59	2.77	– 0.17	0.18	– 0.44
56	"Fertilizers, manufactured"	0.0306	17.87*	– 71.81*	7.08*	1.14	– 89.11*
57	"Explosives and pyrotechnic products"	0.0618	6.85*	– 2.28*	– 0.27**	0.09	2.46
58	"Plastic materials, etc."	0.9338	2.41*	– 2.02	0.08	– 0.006	3.87
59	"Chemical materials and products"	1.1902	3.23	– 17.89	0.98	– 1.16	11.21
6	"Sugar, sugar preparations and honey"	0.0997	4.57**	4.67	– 1.19	– 0.06	14.9161
61	"Leather, lthr. Manufs., n.e.s"	0.1016	0.78	– 8.32*	– 0.63	– 1.58	47.93

Table 6 (continued)

SITC	Industry	Share	Lnipp	Lnex	Pos	Neg	Constant
62	"Rubber manufactures, n.e.s"	0.1042	5.28**	– 1.43	– 0.05	0.37	0.42
63	"Wood and cork manufactures excluding"	0.0959	4.76*	– 3.51*	0.22	0.07	– 8.17**
64	"Paper, paperboard and manufactures"	0.3715	2.24*	0.28	0.12	0.27	– 3.15
65	"Textile yarn, fabrics, made up arti"	0.1537	0.1	2.79	– 0.84	– 0.71	26.97
66	"Nonmetallic mineral manufactures"	0.1073	– 0.5	– 3.46	0.46	– 0.02	1.75
67	"Iron and steel"	0.6101	0.43	– 1.66*	0.08	– 0.14*	9.68*
68	"Nonferrous metals"	0.0363	– 3.27	0.95	– 4.85	– 5.15	176.19
69	"Manufactures of metal, n.e.s"	0.3418	1.89	– 2.46	0.06	– 0.12	6.65
71	"Machinery, other than electric"	7.3861	0.81*	– 0.83**	– 0.009	– 0.1	11.4*
72	"Electrical machinery and apparatus"	2.959	3.14	6.18	2.94	4.13	– 115.3
73	"Transport equipment"	4.2956	3.18*	3.34**	0.03	0.69	– 8.98
81	"Sanitary, plumbing, heating and lig"	0.0337	3.68*	– 5.94*	0.91*	0.53	– 21.4**
82	"Furniture"	0.0475	3.42*	– 0.43	– 0.07	0.09	– 1.36
83	"Travel goods, handbags and similar"	0.0086	10.43*	– 6.10*	1.24**	1.54*	– 53.88*
84	"Clothing"	0.0713	7.36*	2.34**	0.14	1.02*	– 29.09*
86	"Scientif & control instrum"	1.8958	2.01	– 0.75	– 0.25	– 0.23	15.69
89	"Miscellaneous manufactured articles"	1.0422	3.41*	0.14	– 0.11	0.12	1.78
9	"Miscellaneous food preparations"	0.1702	4.01	0.57	– 0.23	0.11	1.16
93	"Special transact. Not class. Accord"	4.0659	3.20*	2.17	0.69	1.16**	– 29.5**

*Significance at 5% and **significance at 10

of eight industries, there is evidence of asymmetric effects in the short run. On the other hand, in a total of six exporting industries, there is evidence of the asymmetric impact of E.R. volatility in long run (Table 10).

The results based on the linear approach to cointegration indicate that increasing exchange rate volatility could have both positive and negative impacts on trade flows depending upon the risk behavior of the investors. In the case of risk-averse behavior, investors are supposed to limit trading activities, while in the case of risk-loving behavior, investors go for exports and imports to avoid future income loss. Thus, in the case of Pakistan's imports from the USA, many small industries were affected negatively; however, three industries are important which were affected negatively in response to exchange rate volatility. It includes "metalliferous ores and metal scrap", "electrical machinery and apparatus" and "Scientif & control instrum, photograph".

Table 7 Diagnostics associated with estimates of nonlinear import models in Table 6

SITC	Industries	*F* stat	ECM	*R* sq	LM	RESET	Wald-S	Wald-L	CU	CU Q
5	Fruit and vegetables	1.29	0.39 (0.72)	0.98	0.05	1.23	14.68*	0.3	S	S
6	Sugar, sugar preparations and honey	5.93*	– 0.80 (4.30)**	0.92	0.4	1.98	7.87*	5.36**	S	S
9	Miscellaneous food preparations	1.7	– 0.29 (2.18)**	0.73	0.89	0.78	0.02	0.23	S	S
11	Beverages	10.14*	– 0.48 (1.21)	0.96	0.01	0.49	10.38*	2.02	S	S
12	Tobacco and tobacco manufactures	8.85*	– 2.60 (0.91)	0.95	0.039	5.43	0.68	3.44	S	S
21	Hides, skins and fur skins, undress	3.81**	0.07 (0.19)	0.65	0.1	11.67	0.54	3.29	S	US
22	Oil seeds, oil nuts and oil kernels	4.46*	– 1.36 (3.78)**	0.62	0.04	0.27	3.46	2.75	S	S
23	Crude rubber including synthetic an	7.10*	– 1.76 (5.09)**	0.97	0.26	2.91	5.61**	0.26	S	S
24	Wood, lumber and cork	2.16	– 0.57 (1.42)	0.94	0.31	8.99	2.97	0.21	S	S
25	Pulp and paper	5.60*	– 0.57 (– 3.16)**	0.96	0.12	4.95	1.41	2.65	S	S
26	Textile fibers, not manufactured, a	8.15*	– 1.44 (5.87)**	0.96	0.003	1.19	3.86	6.66*	S	S
27	Crude fertilizers and crude mineral	4.62*	– 0.81 (3.55)**	0.96	0.08	0.91	0.0008	0.78	S	S
28	Metalliferous ores and metal scrap	2.45	– 0.12 (1.35)	0.94	0.36	0.39	0.36	5.60**	S	S
29	Crude animal and vegetable material	4.30*	– 1.95 (3.64)**	0.99	0.21	0.07	1.85	1.9	S	US
32	Coal, coke and briquettes	0.85	– 0.36 (1.96)**	0.82	0.78	2.61	0.1	0.2	US	US
33	Petroleum and petroleum products	3.34	– 1.33 (3.99)**	0.51	0.55	3.55	8.31*	2.36	S	US
34	Gas, natural and manufactured	6.33*	– 1.78 (5.27)**	0.71	0.74	0.005	10.02*	0.01	S	S
41	Animal oils and fats	4.80*	– 1.67 (3.13)**	0.81	0.98	11.29	0..04	0.01	S	S
42	Fixed vegetable oils and fats	3.41	– 0.65 (3.45)**	0.43	0.72	1.46	3.14	0.35	US	US
43	Animal and vegetable oils and fats,	2.33	– 1.96 (4.43)**	0.65	0.06	0.29	1.46	1.59	S	US
51	Chemical elements and compounds	3.38	– 2.87 (1.51)	0.87	0.01	0.09	1.23	0.25	S	S
52	Crude chemicals from coal, petroleum	2.88	– 1.11 (4.02)**	0.5	0.91	1.24	1.94	0.34	S	S
53	Dyeing, tanning and coloring mater	3.97**	– 0.73 (4.30)**	0.7	0.79	0.34	0.235	0.53	S	S
54	Medicinal and pharmaceutical products	8.44*	– 3.90 (5.03)**	0.98	0.6	1.32	1.54	1.007	S	US
55	Perfume materials, toilet & cleansi	1.71	– 0.23 (2.00)**	0.98	0.92	2.51	1.33	10.03*	S	S
56	Fertilizers, manufactured	6.70*	– 1.09 (5.09)**	0.94	0.99	9.84	1.24	5.51**	S	S
57	Explosives and pyrotechnic products	6.03*	– 2.55 (5.99)**	0.73	0.03	0.06	0.024	0.41	S	S

Table 7 (continued)

SITC	Industries	*F* stat	ECM	*R* sq	LM	RESET	Wald-S	Wald-L	CU	CU Q
58	Plastic materials, etc.	3.81**	– 0.62 (3.87)**	0.78	0.84	3.49	6.73*	5.38**	US	S
59	Chemical materials and products	1.45	– 0.08 (0.29)	0.82	0.06	1.85	0.35	0.25	S	S
61	Leather, lthr. Manufs., n.e.s & dre	4.45*	– 0.83 (3.50)**	0.85	0.59	2.39	0.69	4.33**	S	S
62	Rubber manufactures, n.e.s	2.39	– 0.62 (3.22)**	0.56	0.61	0.09	0.07	9.50*	US	S
63	Wood and cork manufactures excluding	3.88**	– 1.03 (4.16)**	0.83	0.19	0.25	3.87**	5.31**	S	US
64	Paper, paperboard and manufactures	4.26*	– 1.77 (3.57)**	0.95	0.38	4.91	0.04	2.36	S	S
65	Textile yarn, fabrics, made up arti	2.48	– 0.76 (1.63)	0.94	0.06	3.01	1.97	0.06	S	S
66	Nonmetallic mineral manufactures,	2.53	– 0.79 (2.13)**	0.89	0.08	2.59	1.09	7.16*	S	S
67	Iron and steel	10.00*	– 1.48 (7.06)**	0.9	0.16	9.75	20.55*	18.90*	S	S
68	Nonferrous metals	4.50*	– 0.59 (2.35)**	0.93	0.69	0.01	0.05	3.11	S	US
69	Manufactures of metal, n.e.s	2.23	– 0.65 (3.21)**	0.76	0.81	0.05	3.97**	0.44	US	S
71	Machinery, other than electric	6.76*	– 1.67 (5.31)**	0.93	0.03	0.29	0.008	5.16**	S	S
72	Electrical machinery and apparatus	5.99*	– 0.29 (0.76)	0.95	0.02	0.42	0.13	0.18	S	S
73	Transport equipment	5.09*	– 1.24 (3.31)**	0.91	0.88	2.05	90.74*	0.24	S	S
81	Sanitary, plumbing, heating and lig	6.01*	– 1.12 (4.96)**	0.75	0.04	0.53	2.35	0.81	S	S
82	Furniture	4.37*	– 1.23 (5.21)**	0.68	0.25	0.02	0.07	0.23	S	S
83	Travel goods, handbags and similar	7.75*	– 2.26 (6.04)**	0.83	0.67	7.18	0.03	0.79	S	S
84	Clothing	16.92*	– 1.79 (8.56)**	0.9	0.01	0.71	10.55*	1.13	S	S
86	Scientif & control instrum, photogr	8.58*	– 0.64 (2.13)**	0.99	0.08	1.12	3.08	1.59	US	S
89	Miscellaneous manufactured articles	4.73*	– 1.14 (4.67)**	0.95	0.25	1.82	3.91**	2.68	S	S
93	Special transact. Not class. Accord	4.41*	– 1.57 (3.02)**	0.97	0.19	0.93	9.05*	0.95	S	US

n.e.s not elsewhere specified. The critical values for upper and lower bounds for 5% and 10% are 2.86–4.01 and 2.45–3.52, respectively; LM is the Lagrange multiplier test of residual serial correlation. It is Chi-square distributed with one degree of freedom. Ramsey RESET test is used for functional form. It is also Chi-square distributed with one degree of freedom. Its critical values at 5% (1%) significance are 3.84 (6.63). These critical values are also used for the Wald test since they also have a Chi-square distribution with one degree of freedom. The number inside the parenthesis is next to the coefficients which are the absolute values of *t* ratios

*Significance at 5% and **significance at 10%

Table 8 Short-run estimates of nonlinear ARDL of export demand model

SITC	Industry	Share	ΔPOS	ΔPOS_{t-1}	ΔPOS_{t-2}	ΔPOS_{t-3}	ΔNEG	ΔNEG_{t1}	ΔNEG_{t2}	ΔNEG_{t3}
21	"Hides, skins and fur skins, undress"	0.0004	0.58				0.2	0.76	0.09	− 2.88**
26	"Textile fibers, not manufactured"	0.4321	− 0.08	0.26	− 0.11	0.46*	0.12	0.38	0.86*	
29	"Crude animal and vegetable material"	0.005	0.33				0.64*			
5	"Fruit and vegetables"	0.0717	− 0.09	− 0.38	− 0.19	− 0.3	0.26**	− 0.27	0.07	0.32
54	"Medicinal and pharmaceutical products"	0.0029	0.61	− 0.09	− 1.05**	− 0.91**	0.41	0.14	− 0.98	
55	"Perfume materials & toilet"	0.0133	− 0.44				− 0.15			
6	"Sugar, sugar preparations and honey"	0.4616	0.48	− 1.14			0.66	− 1.67*	0.38	0.57
61	"Leather, lthr. Manufs., n.e.s"	0.1003	0.13	− 0.27**	0.34*	− 0.07	0.01	0.38*	− 0.22	0.29*
63	"Wood and cork manufactures excluding"	0.0052	0.34*	− 0.24	− 0.88*	− 0.30*	0.05	0.45*	− 1.22*	
65	"Textile yarn, fabrics, made up arti"	19.8345	0.02				0.03	− 0.07*		
67	"Iron and steel"	0.2154	− 1.14				0.14			
69	"Manufactures of metal, n.e.s"	0.4354	− 0.008	0.06			0.009	− 0.08**		
71	"Machinery, other than electric"	0.0502	0.04				− 0.05			
72	"Electrical machinery & apparatus"	0.048	− 0.12	− 0.86			0.2	− 0.26	− 1.08	1.55*
73	"Transport equipment"	0.0464	− 0.79	0.58	− 0.01	2.36*	− 0.34	0.62	− 1.04	− 1.14
81	"Sanitary, plumbing & heating"	0.2617	− 0.27				− 0.29	0.78*	− 0.23	
82	"Furniture"	0.772	− 1.39*	1.93*			− 0.05	0.54	0.78**	0.65*
85	"Footwear"	0.0717	− 0.19	0.25	− 0.48*	− 0.34*	− 0.01	− 0.50*	0.19	
86	"Scientif & control instrum, photogr"	1.3334	0.07	0.02	− 0.19*	− 0.16**	0.06	0.07	0.11	
89	"Miscellaneous manufactured articles"	1.6323	− 0.21				− 0.18*	− 0.05	0.16*	
9	"Miscellaneous food preparations"	0.0558	− 0.1	0.96*	0.65	0.32	− 0.24**	0.64**	0.73	− 0.17
93	"Special transact. Not class. Accord"	0.5049	− 0.09				− 0.16**			

*Significance at 5%; **significance at 10%

Table 9 Long-run coefficients of nonlinear ARDL for export demand model

SITC	Industry	Share	Lnipus	Lnex	POS	Neg	Constant
21	"Hides, skins and fur skins, undress"	0.0004	4.17	5.62	0.68	1.49*	– 53.9*
26	"Textile fibers, not manufactured"	0.4321	– 0.03	– 2.24**	– 0.19	– 0.73*	18.8*
29	"Crude animal and vegetable material"	0.005	45.47	– 22.09	– 1.29	– 2.5	– 84.37
5	"Fruit and vegetables"	0.0717	8.12	– 20.7*	2.35**	0.41	– 45.37
54	"Medicinal and pharmaceutical products"	0.0029	4.36	– 11.4**	1.86*	0.90**	– 43.3**
55	"Perfume materials & toilet"	0.0133	– 1.37	5.53	– 0.52	– 0.17	10.79
6	"Sugar, sugar preparations and honey"	0.4616	4.24	– 0.77	0.96*	0.83*	– 40.8**
61	"Leather, lthr. Manufs., n.e.s"	0.1003	– 3.82	– 4.05	– 0.01	– 0.05	37.1
63	"Wood and cork manufactures excluding"	0.0052	3.94*	– 6.57*	– 1.41*	0.81*	– 40.53*
65	"Textile yarn, fabrics, made up arti"	19.8345	5.22*	– 0.68	0.05	0.02	– 9.34
67	"Iron and steel"	0.2154	0.14	18.96	– 1.6	0.28	4.63
69	"Manufactures of metal, n.e.s"	0.4354	1.78**	1.29	– 0.06	0.04	– 0.28
71	"Machinery, other than electric"	0.0502	2.39	– 0.09	0.05	– 0.07	– 6.97
72	"Electrical machinery & apparatus"	0.048	– 0.84	6.66	1.3	0.76	– 7.32
73	"Transport equipment"	0.0464	6.57	92.4*	– 10.22*	– 1.21	40.77
81	"Sanitary, plumbing & heating"	0.2617	– 3.08	2.76	– 0.48	– 0.68*	23.1
82	"Furniture"	0.772	3.00**	6.04*	– 1.38*	– 1.06*	23.01*
85	"Footwear"	0.0717	0.36	– 6.75	0.86**	– 0.07	– 7.52
86	"Scientif & control instrum, photogr"	1.3334	– 1.44	– 5.84*	0.54	– 0.23	13.64
89	"Miscellaneous manufactured articles"	1.6323	2.24	– 3.03	– 0.7	– 1.07	32.8
9	"Miscellaneous food preparations"	0.0558	6.81*	3.53*	– 0.85*	– 0.58*	– 6.09
93	"Special transact. Not class. Accord"	0.5049	– 1.12	0.46	– 0.18	– 0.31	17.23

*Significance at 5%; **significance at 10%

These three industries have a share of 4.9% and 2.9% and 1.8%, respectively. The results indicate that traders reduced imports in the face of increasing exchange rate uncertainty. Three important industries that got affected positively were textile fibers, not manufactured (5.5%), and transport equipment (4.3%) and chemical materials and products. However, in the case of Pakistan's exports to the USA, an interesting pattern that can be found is that a negligible number of industries were affected negatively. However, the industries that got benefited from exchange rate volatility included industries such as textile fibers, not manufactured", furniture and footwear. In the case of the nonlinear approach, the results indicate that there is evidence of

Table 10 Diagnostics associated with estimates of nonlinear export models in Table 9

SITC	Industry	F.STAT	ECM	R sq	LM	RESET	Wald-S	Wald-L	CU	CU Q
5	Fruit and vegetables	4.20*	− 0.59 (2.54)**	0.93	0.14	11.46	0.11	0.75	S	S
6	Sugar, sugar preparations and honey	7.41*	− 2.15 (5.99)**	0.94	0.86	5.51	2.42	0.38	S	S
9	Miscellaneous food preparations	3.88**	− 2.60 (4.35)**	0.99	0.02	6.82	1.07	3.85**	S	US
21	Hides, skins and fur skins, undress	8.40*	− 2.06 (5.28)**	0.92	0.003	0.47	1.11	0.26	S	S
26	Textile fibers, not manufactured	10.51*	− 2.03 (6.28)**	0.98	0.01	0.29	2.5	0.07	S	S
29	Crude animal and vegetable material	1.87	0.25 (0.93)**	0.93	0.07	4.74	0.04	0.16	S	US
54	Medicinal and pharmaceutical products	3.29	− 1.67 (3.44)**	0.76	0.21	1.17	6.14**	1.34	S	S
55	Perfume materials & toilet	3.51	− 0.85 (3.95)**	0.73	0.17	0.23	1.14	0.54	S	S
61	Leather, lthr. Manufs., n.e.s	6.25*	− 0.42 (3.41)**	0.95	0.32	0.37	9.01*	5.81**	S	S
63	Wood and cork manufactures excluding	15.61*	− 1.32 (8.22)**	0.98	0.49	7.86	37.93*	3.04	S	S
65	Textile yarn, fabrics, made up arti	3.23	− 0.14 (2.77)**	0.99	0.5	1.43	14.59*	5.27**	S	S
67	Iron and steel	3.04	− 0.71 (4.04)**	0.46	0.82	0.04	2.02	0.03	S	S
69	Manufactures of metal, n.e.s	3.38	− 0.44 (4.26)**	0.98	0.39	3.92	30.02*	0.9	S	US
71	Machinery, other than electric	3.94**	− 0.77 (4.23)**	0.75	0.72	4.39	0.59	0.32	US	US
72	Electrical machinery & apparatus	4.43*	− 0.52 (3.32)**	0.91	0.29	2.33	0.67	0.05	S	S
73	Transport equipment	16.52*	− 0.37 (3.43)**	0.98	0.02	3.88	18.53*	2.89	S	US
81	Sanitary, plumbing & heating	3.24	− 1.23 (3.40)**	0.9	0.85	1.27	1.02	5.80**	S	S
82	Furniture	4.93*	− 2.60 (4.18)**	0.99	0.01	3.37	6.04**	3.81	S	S
85	Footwear	7.90*	− 0.95 (5.81)**	0.97	0.85	0.24	11.47*	0.06	S	S
86	Scientif & control instrum, photogr	3.36	− 0.64 (2.96)**	0.97	0.14	2.79	0.88	0.33	S	US
89	Miscellaneous manufactured articles	5.43*	− 0.15 (1.71) *	0.96	0.19	9.15	0.42	5.46**	S	S
93	Special transact. Not class. Accord	2.06	− 0.52 (3.22)**	0.74	0.22	0.73	0.23	3.91**	S	S

n.e.s not elsewhere specified

The critical values for upper and lower bounds for 5% and 10% are 2.86–4.01 and 2.45–3.52, respectively; LM is Lagrange multiplier test of residual serial correlation. It is Chi-square distributed with one degree of freedom. Ramsey RESET test for functional form. It is also Chi-square distributed with one degree of freedom. Its critical value at 5% (1%) significance is 3.84 (6.63). These critical values are also used for Wald test since they also have Chi-square distribution with one degree of freedom. Number inside the parenthesis is next to the coefficients which are the absolute values of t ratios

*Significance at 5%; **significance at 10%

asymmetric effect, i.e., with regard to the impact of positive and negative volatility on both exports and imports. The results vary concerning both the selected exporting and importing industries. Finally, the results indicate that mostly importing industries were affected negatively in comparison with the exporting industries. The results may point to the fact that traders in Pakistan are likely to be affected more by increasing exchange rate volatility than those counterparts in the USA who import from Pakistan as exports to the USA were less affected; rather, they were increased.

4 Conclusion

After the collapse of the fixed exchange rate system in 1973, exchange rate volatility became a more debatable topic. A flexible exchange rate system was perceived to have a profound effect on the trade environment as financing uncertainty was associated with a flexible exchange rate. The opponent of the flexible exchange rate system argued that a flexible exchange rate creates uncertainty for trade and is likely to decrease trade activities, while the proponents advocated the flexible exchange rate system since it is a market-oriented approach and maybe traded enhancing. Yet, the empirical studies have come up with evidence that supported both of the views. However, previous studies have examined the effects of uncertain exchange rates on trade flows by using either the aggregate-level trade data or data at the bilateral level. So far, both types of studies were supposed to suffer from aggregation bias. On the other hand, many studies used the data of trade flows at the commodity level but all these studies have a common feature that they presumed a symmetric effect of exchange rate volatility on trade flows, where both increased volatility and decreased volatility should have an identical effect on trade flows.

Many studies in recent years have confirmed that the impact of exchange rate volatility is asymmetric on trade flows, i.e., increased volatility lowers the trade volume while decreased volatility tends to enhance it. In this study, we interrogate this assumption and claim that does exchange rate volatility has asymmetric effects in the case of Pakistan. Hence, the objective of this study was to investigate the asymmetric effects of exchange rate volatility on trade flows at the industry level. This study has taken 48 importing industries of Pakistan and 23 exporting industries to analyze the asymmetric effects of exchange rate volatility. Our findings could "be best summarized by saying that short-run adjustment asymmetry, short-run asymmetric effects, short-run cumulative or impact asymmetry, and long-run asymmetric effects were found in half (1/2) of importing industries and exporting industries of Pakistan. In the case of importing industries, the short-run adjustment asymmetry is more dominant compared to long-run asymmetric effects as in the long run, fewer importing industries were affected by positive and negative volatility. In the case of exporting industries, there is significant evidence of both short-run asymmetric effects and long run asymmetric effects in Pakistan. It indicates that when the currency depreciates traders prefer to export more goods but it is not true in all cases. Both small and large industries respond to the asymmetric effect of exchange rate volatility. Our approach helps identify the industries that respond positively and those which respond negatively to both increased and decreased exchange rate volatility. The asymmetric effects seem to be industry-specific and have implications for other industries in other countries. Further research in this direction is needed to arrive at a general conclusion."

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Appendix

Data definition and sources

The empirical analysis was based on annual data over the period of 1981–2018. The annual data came from the following sources:

(a) World Bank.
(b) International Financial Statistics.

Definition of variables

1. "Pakistan's export volume of industry *i* to the USA. Nominal figures come from the source a. In the absence of an annual price level for each industry, we follow Bahmani-Oskooee and Ardalani (2006) and deflate each industry trade value by Pakistan's export unit value. The data of exports unit value come from the source a."
2. "Mi Pakistan's import volume of industry i from the USA. Nominal import data for each industry come from the source a. In the absence of an annual import price level for each industry, again, we follow Bahmani-Oskooee and Ardalani (2006) and deflate each industry import value by Pakistan's import unit value index. Pakistan's import unit value index comes from the source a."
3. IP_t^{Pak} Pakistan's industrial production index is used as a measure of economic activity. Data come from source b.
4. IP_t^{US} industrial production index of the USA. Data come from source b.
5. "REX_t is a real bilateral exchange rate in terms of US currency. REX is a real bilateral exchange rate between the US dollar and the Pakistani rupee. It is defined as (PUSNEX/PPAK), where PUS (PPAK) is the price level in the USA (Pakistan) and NEX is the nominal bilateral exchange rate. Thus, an increase in REX is a reflection of the real depreciation of the Pakistani currency. CPI data for both countries and the nominal exchange rate data come from source b."
6. "V_t is the volatility of the real bilateral exchange rate, REX. Following Bahmani-Oskooee and Hegerty (2009), V is calculated as the standard deviation of the 12-monthly real exchange rate within that each year. Monthly CPI data for both countries and the nominal exchange rate data come from source b." (Tables 11, 12)

Table 11 Descriptive statistics (Pakistan's exports to the USA)

SITC	Industry	Mean	SD	Max	Min
5	"Fruit and vegetables"	5135.365	2838.241	11,737.59	71.52
6	"Sugar, sugar preparations and honey"	8123.651	10,329.91	34,034.69	11.318
9	"Miscellaneous food preparations"	1912.835	2542.663	12,253.04	5.406
21	"Hides, skins and fur skins, undress"	112.384	202.3703	1102.717	0.1
26	"Textile fibers, not manufactured"	10,389.44	11,192.9	32,219.5	275.972
29	"Medicinal and pharmaceutical products"	8892.517	5805.629	21,722.11	250.384
54	"Perfume materials, toilet & cleansi"	223.4694	189.861	896.751	39.619
55	"Leather, lthr. Manufs., n.e.s & dre"	266.8168	308.6076	1210.929	2.1
61	"Wood and cork manufactures excludin"	8482.726	4809.625	18,184.99	982.551
63	"Textile yarn, fabrics, made up arti"	330.1832	182.9668	816.183	32.211
65	"Iron and steel"	826,034.6	609,309.9	1,825,806	83,827.86
67	"Manufactures of metal, n.e.s"	3818.753	6634.258	23,903.8	0.1
69	"Machinery, other than electric"	20,593.39	10,103.35	35,083.87	5489.108
71	"Electrical machinery and apparatus"	1483.741	1523.625	5503.853	33.173
72	"Transport equipment"	2550.614	2391.048	8291.277	71.014
73	"Sanitary, plumbing, heating and lig"	1971.297	2486.209	9402.162	0.1
81	"Furniture"	1340.187	3247.855	18,771.77	12.21
82	"Footwear"	36,100.35	39,703.7	111,420.9	160.212
85	"Scientif & control instrum, photogr"	5250.812	4206.164	14,802.92	45.511
86	"Miscellaneous manufactured articles"	928,657.8	667,007.5	1,932,434	28,090.1
89	"Special transact. Not class. Accord"	1055.846	1247.352	5142.663	0.1

Table 12 Descriptive statistics (Pakistan's imports from the USA)

SITC	Importing industry	Mean	SD	Max	Min
5	Fruit and vegetable	9828.27	17,681.40	89,059.32	41.72
6	Sugar, sugar preparations and honey	893.76	1476.77	6029.70	4.95
9	Miscellaneous food preparations	3082.47	2608.12	8840.41	291.56
11	Beverages	202.13	336.73	1402.07	2.47
12	Tobacco and tobacco manufactures	2328.18	5008.52	30,264.10	0.20
21	Hides, skins and fur skins, undress	447.65	584.92	2578.61	0.20
22	Oil seeds, oil nuts and oil kernels	9490.81	30,524.13	135,710.42	0.10
23	Crude rubber including synthetic an	1436.38	1630.16	5155.25	67.50
24	Wood, lumber and cork	6796.55	13,905.67	51,472.18	0.30
25	Pulp and paper	10,507.68	6726.16	26,399.88	528.64
26	Textile fibers, not manufactured, a	91,874.36	87,067.15	278,254.20	8178.45
27	Crude fertilizers and crude mineral	2639.94	2007.54	8100.26	383.03
28	Metalliferous ores and metal scrap	44,833.40	61,317.55	190,479.37	954.96
29	Crude animal and vegetable material	2341.53	1958.10	7417.79	449.19
32	Coal, coke and briquettes	1662.53	2833.99	10,226.45	0.10
33	Petroleum and petroleum products	6497.05	14,858.50	86,759.69	790.96

Table 12 (continued)

SITC	Importing industry	Mean	SD	Max	Min
34	Gas, natural and manufactured	29.06	84.33	497.88	0.10
41	Animal oils and fats	11,100.88	13,925.24	49,547.56	0.20
42	Fixed vegetable oils and fats	49,301.93	62,219.57	233,490.75	187.34
43	Animal and vegetable oils and fats,	303.47	567.75	2365.89	0.10
51	Chemical elements and compounds	26,426.32	10,112.64	50,614.32	6384.22
52	Crude chemicals from coal, petroleum	1633.84	3231.42	15,183.88	0.10
53	Dyeing, tanning and coloring mater	2408.86	1424.36	5727.54	422.47
54	Medicinal and pharmaceutical products	21,841.27	11,291.88	61,471.73	7166.58
55	Perfume materials, toilet & cleansi	5719.43	6137.91	20,390.82	752.94
56	Fertilizers, manufactured	44,358.33	43,511.71	129,483.86	0.10
57	Explosives and pyrotechnic products	2732.57	3429.41	18,471.91	181.01
58	Plastic materials, etc.	16,938.12	9659.25	38,760.70	3984.99
59	Chemical materials and products	17,247.86	10,536.93	46,090.98	5999.35
61	Leather, lthr. Manufs., n.e.s & dre	450.31	663.82	4112.34	46.37
62	Rubber manufactures, n.e.s	2681.04	2586.78	12,269.79	226.28
63	Wood and cork manufactures excluding	1668.72	1981.22	7929.26	45.87
64	Paper, paperboard and manufactures	7935.04	5987.32	27,781.35	790.30
65	Textile yarn, fabrics, made up arti	6714.11	5203.32	20,522.32	1012.40
66	Nonmetallic mineral manufactures,	2179.97	1030.76	5282.72	809.25
67	Iron and steel	19,956.03	9944.23	43,616.28	7647.48
68	Nonferrous metals	3061.77	2436.63	8298.57	338.33
69	Manufactures of metal, n.e.s	8787.59	5509.48	19,564.41	2037.36
71	Machinery, other than electric	174,810.65	83,245.66	317,293.44	60,798.24
72	Electrical machinery and apparatus	79,608.17	57,151.71	226,138.74	17,009.69
73	Transport equipment	167,979.00	198,093.57	845,881.18	41,341.62
81	Sanitary, plumbing, heating and lig	697.43	550.23	2733.62	171.95
82	Furniture	1071.04	891.40	3566.65	117.31
83	Travel goods, handbags and similar	143.25	130.51	617.45	2.98
84	Clothing	954.03	1023.26	4482.01	38.13
86	Scientif & control instrum, photogr	32,061.97	26,734.06	111,468.68	5026.89
89	Miscellaneous manufactured articles	13,222.20	10,769.31	41,327.31	3083.91
93	Special transact. Not class. Accord	57,633.96	60,749.75	211,133.54	4019.10
	Independent variables	**Mean**	**SD**	**Max**	**Min**
	Industrial production (Pakistan)	4.1314576	3.5042146	4.8154631	2.908363
	Real exchange rate	3.9227465	3.4288659	4.6603986	2.292535
	Exchange rate volatility	0.2442597	0.3855322	2.0314984	− 33.92071
	Industrial production index (USA)	4.4591752	2.9958427	4.7146753	3.971402

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