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Research Article

Asymmetric Exchange Rate Pass-Through to Consumer Prices in Ghana: Evidence from EMD-NARDL Approach

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This paper analyses the US dollar exchange rate pass-through to consumer prices in Ghana from January 1990 to January 2020 using the empirical mode decomposition-based nonlinear autoregressive distributed lags model (EMD-NARDL). This model eliminates the noise component of the underlying data and captures the short- and long-run nonlinearities. We find evidence of cointegration between denoised series of consumer prices and exchange rate and asymmetric pass-through in both the short- and long-run. Specifically, exchange rate pass-through was found to be in the long-run incomplete in the period of depreciation and statistically zero pass-through in the period of appreciation. In the short-run, the exchange rate pass-through in periods of depreciation is near complete; that is, 81% against 74% in periods of appreciation. We recommend that monetary authorities consistently monitor exchange rate behaviour and maintain efficient exchange rate management policies to ensure stable consumer prices. This could be achieved through proper and timely policy interventions using the available monetary policy tools such as foreign exchange reserves.

1. Introduction

The challenge of maintaining low and stable inflation continues to persist in most developing countries, especially, open economies. The extent to which domestic prices adjust to exchange rate changes is key in understanding inflation dynamics in these economies. Most especially, the exchange rate provides an important transmission channel for monetary policy, in addition to the standard aggregate demand channel [1]. Exchange rate pass-through (ERPT) which denotes the transmission of exchange rate movements to domestic prices has thus become important for the conduct of monetary policy. Evidence of "disconnect" between exchange rates and prices would imply a greater degree of insulation and greater effectiveness of the monetary policy. Earlier literature assumed that exchange rate pass-through to consumer prices is linear and symmetrical but there is growing evidence that exchange rate pass-through is nonlinear and asymmetric to consumer prices [2–5]. As noted by Jammazi, et al. [6]; the potential of nonlinearity and asymmetries are mainly driven by economic episodes, geopolitics, business cycle structure, and heterogeneity in economic agents and dynamics in the economic fundamentals. This different episodic in exchange rate dynamics present different implications for macroeconomic policy on prices [4, 7, 8]. The transitory fluctuations in consumer prices and exchange rates influence the monetary policy implication of the observed relationship as it has been recommended that monetary policy should respond to changes to core consumer price [9, 10]. It is therefore imperative to separate noise from trend to minimize its impact on the relationship and also improve its policy implications.

However, the evidence of nonlinearity and asymmetric effect of exchange rate on consumer prices have been restricted to noisy data and we are oblivious of the dynamics of denoise data. In this paper, we analyse the nonlinearity and asymmetry in the denoised exchange rate pass-through to denoised consumer prices in Ghana from 1990 to 2020. The evidence available in the literature shows that exchange rate pass-through is very low for advanced economies with a median closer to zero but generally high for small, open emerging market, and developing economies with flexible exchange rate regime [11, 12]. Ghana fits well into this description and Ghana's local currency, the cedi, continues to see substantial swing, mainly due to dependency on primary commodities and imports [2].

Exchange rate pass-through in Ghana has been fairly examined in standalone studies or as part of cross-country studies. There seems to be a conclusion from linear and symmetric studies that exchange rate pass-through in Ghana is incomplete [1, 13–15]. There is also evidence that there is an asymmetric effect in exchange rate pass-through in Ghana [4, 16, 17].

The purpose of this study is to expand the discussion on nonlinearity and asymmetries in exchange rate pass-through to consumer prices by combining empirical mode decomposition and the nonlinear autoregressive distributed lag model (EMD-NARDL). The advantage of this approach is that it allows us to denoise the raw data and to discriminate between the short- and long-run asymmetric responses of consumer price to both positive and negative changes in exchange rates after the noise components from the original data have been expunged (i.e. core prices and exchange rates).

Empirical Mode Decomposition (EMD) has been suggested by Huang et al. [18] to decompose the nonlinear and nonstationary signal into multiple intrinsic mode functions (IMF), without requiring a priori basis function, unlike wavelet. Thus, the EMD denoising method is a fully data-driven approach since the decomposition of the EMD is based on the local characteristics and time scale of the data. The EMD decomposes into a sum of IMFs. An IMF is a function that must satisfy the following two conditions [18]. First, the number of extrema must either be equal to or at most differ by one from the number of zero crossings. And then, the mean values of both the envelope defined by the local maxima and the envelope defined by the local minima, are zero at any point in the data.

While there are studies on the behaviour of exchange rate and consumer prices [19, 20], none of them denoised data to approximate the true relationships between these variables. Denoising consumer prices allow us to concentrate on core consumer price or inflation which is the object of focus by the monetary policy while the exchange rate is smoothed after removing the noise. The denoised series are analysed with the nonlinear autoregressive distributed lag (NARDL) model which is a dynamic error-correction representation. Through the NARDL model, we can derive reliable long-run inferences through bounds tests regardless of the integration orders of the variables in the system [21] and has been employed in recent times [6, 22, 23].

This study makes an important contribution to the existing literature. It is the first study to distinguish noise from the trend of consumer price in the analysis of nonlinearity and asymmetry in exchange rate pass-through using a combination of empirical mode decomposition and nonlinear ARDL. In this way, we are to appropriately quantify the percentage of exchange pass-through to consumer prices devoid of transient effects. Hence, the unique contribution of this study to existing empirical studies is the application of the denoised-NARDL based approach to exchange rate pass-through in the context of a developing country, Ghana that experiences rapid oscillations in its exchange rate and consumer price fundamentals.

The rest of the paper is organized as follows: Section 2 reports the methodology, Section 3 presents data description and source, Section 4 considers the results, and concludes the paper.

2. Methodology

2.1. Empirical Mode Decomposition. EMD is a dyadic filter bank in the frequency domain [24]. The goal of the empirical mode decomposition is to decompose the original data (nonstationary and nonlinear data) into the IMFs and the residue. The EMD is a fully data-driven decomposition method and IMFs are derived directly from the signal itself.

According to Huang et al. [18]; the EMD comprises the following steps:

(1) Initialize the residue to the original time series $r_0(t) = x(t)$ and set the IMF index $k = 1$.

(2) To extract the kth IMF:

(a) initialize $h_0(t) = r_{k-1}(t)$ and the iteration counter $i = 1$
(b) find the local maxima and the local minima of $h_{i-1}(t)$
(c) create the upper envelope $E_u(t)$ by interpolating between the local maxima (lower envelope $E_l(t)$ by interpolating the local minima, respectively)
(d) calculate the mean of both envelopes as follows:

$$m_{i-1}(t) = \frac{E_u(t) + E_l(t)}{2}, \tag{1}$$

(e) subtract the envelope mean from the input time series to obtain the following equation:

$$h_i(t) = h_{i-1}(t) - m_{i-1}(t), \tag{2}$$

(f) verify if $h_i(t)$ satisfies the IMF's conditions:
(i) If $h_i(t)$ does not satisfy the IMF′s conditions, increase $i = i + 1$ and repeat the shifting process from step b
(ii) If $h_i(t)$ satisfies the IMF′s conditions, set $IMF_k(t) = h_i$ and define $r_k(t) = r_{k-1}(t) - IMF_k(t)$

(3) When the residue $r_k(t)$ is either a constant, a monotonic slope or contains only one extremum, stop the process, otherwise continue the decomposition from step 2, setting $k = k + 1$

The original signal can be precisely reconstructed as follows:

$$x(t) = \sum_{i=1}^{n} \mathrm{IMF}_k(t) + r_n(t). \quad (3)$$

Next, we performed thresholding in each IMF to locally exclude low-energy IMF parts that are expected to be significantly corrupted by noise. A direct application of wavelet thresholding in the EMD case translates to

$$\widehat{\mathrm{IMF}}_k(t) = \begin{cases} \mathrm{IMF}_k(t), & \mathrm{IMF}_k(t) \geq T_k, \\ \cdot, & \\ 0, & \mathrm{IMF}_k(t) \leq T_k, \end{cases} \quad (4)$$

for hard thresholding and to

$$\widehat{\mathrm{IMF}}_k(t) = \begin{cases} \mathrm{sgn}(\mathrm{IMF}_k(t))(\mathrm{IMF}_k(t)) - T_k, & \mathrm{IMF}_k(t) \geq T_k, \\ \cdot, & \\ 0, & \mathrm{IMF}_k(t) \leq T_k, \end{cases} \quad (5)$$

for soft thresholding, where, in both thresholding cases, $\widehat{\mathrm{IMF}}_k(t)$ indicates the kth thresholded IMF. The reconstructed denoised series becomes

$$\hat{x}(t) = \sum_{K=M_1}^{M_2} \mathrm{IMF}_k(t) + \sum_{K=M_2+1}^{L} \mathrm{IMF}_k(t), \quad (6)$$

where the introduction of parameters M_1 and M_2 gives us flexibility on the exclusion of the noisy low-order IMFs and on the optional thresholding of the high-order ones, which in white Gaussian noise conditions contain little noise energy.

2.2. Nonlinear Autoregressive Distributed Lag Model (NARDL). The NARDL was introduced by Shin et al. [21] and is an extension of the method introduced by Pesaran et al. [25]. The NARDL offers an opportunity to test asymmetry in shocks (i.e., whether the positive shocks of the independent variables have the same effect as their negative shocks on the dependent variables) [26]. The typical ARDL assumes a symmetric relationship between the dependent and the explanatory variables and thus prevents hidden cointegration to be detected. Time series variables are said to have hidden cointegration if their positive and negative components are cointegrated with each other, while they are not cointegrated in the conventional sense [27]. Thus, NARDL is more appropriate for our research problem as it allows for testing asymmetries in both the short and long run. In the typical ARDL, the linear specification without asymmetric adjustment in the short and long run is stated as follows:

$$\Delta \mathrm{CPI}_t = \alpha + \mathrm{CPI}_{t-1} + \beta \mathrm{EXR}_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta \mathrm{CPI}_{t-i} + \sum_{i=0}^{p} \omega_i \Delta \mathrm{EXR}_{t-i} + \mu_t, \quad (7)$$

where CPI_t represent the log of Ghana's consumer price index and EXR_t is the log of Ghana Cedi-US Dollar exchange rate. The NARDL representation of equation (7) is obtained by the following two steps. First, decompose the exogenous variable EXR_t into the positive and negative partial sum, i.e., EXR_t^+ and EXR_t^- of increase and decreases as follows:

$$\begin{aligned} \mathrm{EXR}_t^+ &= \sum_{j=1}^{t} \Delta \mathrm{EXR}_j^+ = \sum_{j=1}^{t} \max(\Delta \mathrm{EXR}_j, 0), \\ \mathrm{EXR}_t^- &= \sum_{j=1}^{t} \Delta \mathrm{EXR}_j^- = \sum_{j=1}^{t} \min(\Delta EXR_j, 0). \end{aligned} \quad (8)$$

Second, substitute the positive and negative partial sum into equation (7) to obtain

$$\Delta \mathrm{CPI}_t = \alpha + \rho \mathrm{CPI}_{t-1} + \beta^+ \mathrm{EXR}_{t-1}^+ + \beta^- \mathrm{EXR}_{t-1}^- + \sum_{i=1}^{p} \gamma_i \Delta \mathrm{CPI}_{t-i} + \sum_{i=0}^{p} (\omega_i^{\,+} \Delta \mathrm{EXR}_{t-1}^+ + \omega_i^- \Delta \mathrm{EXR}_{t-1}^-) + \mu_t, \quad (9)$$

where the superscripts (+) and (−) are the positive and negative partial sums decomposition, $-\beta^+/\rho$ and $-\beta^-/\rho$ captures the long-run prices adjustment to positive and negative shocks in the exchange rate while $-\omega^+/\rho$ and $-\omega^-/\rho$ captures short-run adjustment. The p and q represent the lag orders for the dependent and the independent variables respectively. The NARDL has several distinctive features which make it preferred to its competing cointegration modes. It assumes the advantages of the typical ARDL, thus performing better in testing for cointegration relationships in small samples and applicable to regressors with different integration orders. Also, NARDL allows one to discriminate between linear cointegration, nonlinear cointegration, and absence of cointegration [28] and test for long- and short-run asymmetries in the dynamics of two cointegrated economic variables [6].

2.3. Data Description and Results. Our study employed time series of a monthly consumer price index (CPI) of Ghana and period average Ghana Cedi to US Dollar exchange rate (EXR) from January 1990 to January 2020 consisting of 361 observations. The two series were extracted from the International Monetary Fund IFS-Statistics Database.

Table 1 summarizes the descriptive statistics and stochastic properties for CPI and EXR.

Panel A of Table 1 shows that Ghana Cedi depreciated against the US dollar over the study period with an average of 1.46% per month. Within the same period, CPI increased from 47.660 to 296.330, representing a growth rate of 0.507% per month. The Ghana Cedi to US dollar exchange rate and CPI averaged GHS1.402 and 78.768 with a standard deviation of 1.514 and 81.413, respectively. All the series depart from normality as indicated by the Jarque–Bera test. The correlation matrix at Panel B shows a high correlation between the exchange rate and CPI.

We examined the unit root properties of the two variables using Augmented Dickey–Fuller and Philips–Perron

Table 1: Descriptive statistics and correlation matrix.

	CPI	EXR
Panel A: Descriptive statistics		
Mean	78.764	1.402
Median	47.660	0.900
Maximum	296.330	5.540
Minimum	1.830	0.030
Standard deviation	81.413	1.514
Skewness	1.098	1.247
Kurtosis	3.118	3.333
Normality	72.794**	95.180**
Probability	[<0.01]	[<0.01}
	Panel B: Correlation matrix	
CPI	1	0.98** [<0.01]
EXR		1

Table 2: Results of unit root and break-points.

	Levels				First difference			
Variables	ADF	PP	Za	Break-point (M)	ADF	PP	Za	Break-point (M)
CPI_t	3.657	3.327	−7.718	199101	−8.457***	−9.506***	−12.765***	199501
EXR_t	4.066	4.633	−3.456	199102	−5.584***	−18.71***	−19.222***	199103

Note: *, **, and ***indicate significant at the 10% level, 5% level, and 1% level, respectively.

Table 3: Results of BDS nonlinearity test.

BDS statistics					Embedding dimension = m
Series	$m = 2$	$m = 3$	$m = 4$	$m = 5$	$m = 6$
EXR_t	0.206***	0.352***	0.454***	0.526***	0.576***
CPI_t	0.206***	0.351***	0.453***	0.525***	0.575***

as well as the Zivot and Andrews [29] structural break test as presented in Table 2. The combination of these tests is to ensure that we accurately conclude that none of the variables in the model is I(2). Especially, ADF and PP performs poorly in the presence of structural breaks and may deceptively prove the variables to be integrated of order one or two when there are one or more breaks in the series. Our data from 1990M01 to 2020M01 cut-through several policy interventions, reforms, and global phenomenon such as the global financial crisis making our data susceptible to structural breaks. The results from all tests show that none of our variables is I(2). Generally, all the identified break were in the year 1991 which can be linked to both economics and political reforms in Ghana.

The presence of time break prompts the nonlinear behaviour of the time series over the study period. We investigated the time series non-linear dependencies using Broock, et al. [30]. Table 3 shows the results of the BDS nonlinearity test. The BDS test rejects the null hypothesis of independent and identically distributed (i.i.d) residuals across various dimensions, which confirms the time series nonlinear dependencies. This outcome strongly confirms nonlinearity in the series and affirms the need to analyse the series within a nonlinear framework. In other words, there is a need to denoise the data other than relying entirely on the original series.

3. Results of the EMD Denoising

We began our analysis by using the EMD threshold to denoise both the consumer price index and exchange rate. The results of the EMD threshold denoising procedure are presented in Figure 1. The monthly denoised series SCPI and SEXR faithful represent the original series CPI and EXR, respectively, immunized against noises. It is obvious from Figure 1 that EXR is the most exposed to drifts, though not very substantial.

This is not surprising as exchange rates are known to be affected by destabilizing behaviour of participants (noise traders and speculators in particular) in currency markets [6, 31, 32]. The fact that our raw data contain some noise components resulting in market frictions and unexpected economic changes, we should expect different sensitivity of consumer prices to exchange rate with the original and denoised data. We analyse both denoised and original series to enable comparison. Notwithstanding, we focus our policy discussion on the denoised series because of its relevance in monetary policy conduct [9, 10].

3.1. Cointegration and Asymmetric Effects Test. Table 4 presents the results of the bounds test of cointegration estimates for each pair of consumer price index and exchange rate

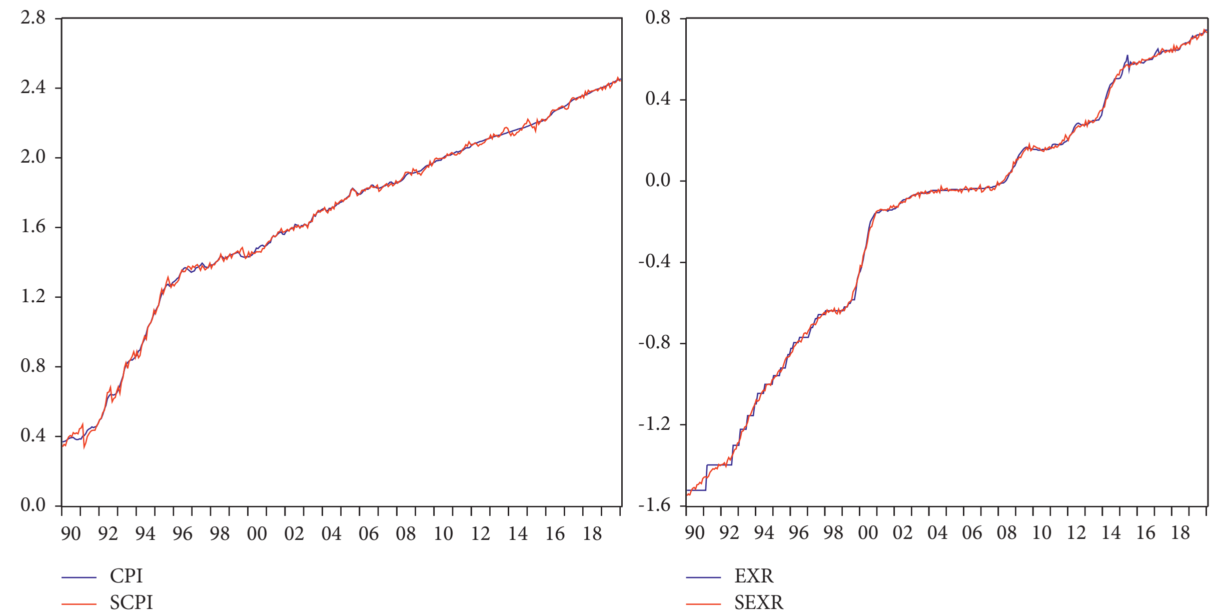

FIGURE 1: EMD denoised series (red) versus original series (blue).

TABLE 4: Results of NARDL Bound test.

Model	Specification	Statistics	Significance (%)	PP-bounds I (0)	PP-bounds I (1)	Narayan-bounds I (0)	Narayan-bounds I (1)
$CPI_t/EXR_t^+;EXR_t^-$	NARDL (2, 0, 0,)	2.148	10	2.63	3.35	2.713	3.45
			5	3.1	3.87	3.235	4.053
			1	4.13	5.00	4.358	5.393
$SCPI_t/SEXR_t^+;SEXR_t^-$	NARDL (1, 4, 2,)	4.365**	10	2.63	3.35	2.713	3.45
			5	3.1	3.87	3.235	4.053
			1	4.13	5.00	4.358	5.393

Note: *, **, and ***indicate significant at the 10% level, 5% level, and 1% level, respectively.

TABLE 5: Results of Asymmetric effects test.

Null hypothesis	Long run	Short run
Symmetric effect of exchange rate on consumer prices	$\chi^2(1) =$ 1190.83 [<0.01]	$\chi^2(1) = 58.59$ [<0.01]

(denoised vs. original series) and perform the Wald tests for short- and long-run symmetry where cointegration is detected. We confirm cointegration in NARDL (1, 4, 2,) model at a 5% significance level for the denoised series. However, no cointegration was detected between the exchange rate and consumer prices of the raw series. This no cointegration corroborated prior studies that relied on raw data series to study the relationship between exchange rate and consumer prices in Ghana. Frimpong and Adam [1] found no significant relationship between the exchange rate and consumer prices in the long-run. Sanusi [15] also found no long-run relationship between the exchange rate and consumer prices. Table 5 presents the results of the NARDL asymmetric effects. We found statistically significant asymmetric effects of exchange rate on consumer prices, both in the long run and in the short-run.

3.2. Long-Run, Short-Run, Dynamic Asymmetric Multiplier, and Dynamic Stability. Table 6 shows the long-run and short-run asymmetric effect of exchange rate on consumer prices. Based on the asymmetric long-run results presented in Panel A of Table 6, an increase of exchange rate (depreciation of Ghana Cedi) by 1% results in an increase of consumer prices by 0.539% at a 5% significance level. On the contrary, a decrease in the exchange rate (appreciation of the Ghana Cedi) had a statistically insignificant effect on consumer prices. The finding suggests that there is an asymmetry in exchange pass-through in Ghana in the long-run which is incomplete but relatively high, about 53.9%, during periods of depreciation. This finding contradicts the symmetry found by Maka [17] and Kassi et al. [4] but corroborates Amoah and Aziakpono [16] in which incomplete pass-through was found in periods of depreciation than in periods of appreciation; that is 53 against 3 percent. This can be explained by the binding quantity constraint and menu cost theories. The theories hold that exchange is likely to be higher in periods of depreciation compared to periods of appreciation.

Regarding the short-run results presented in Panel B of Table 6, we note that a 1% depreciation of the Ghana Cedi to

Table 6: Long run and short run, NARDL (1,4,2).

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Panel A: Long run				
$SEXR_t^+$	0.543**	0.230	2.364	0.018
$SEXR_t^-$	0.2132	0.703	0.303	0.762
C	1.098***	0.312	3.512	0.001
Panel B: Short run				
$\Delta SEXR_t^+$	0.810***	0.098	8.273	0.000
$\Delta SEXR_{t-1}^+$	−0.235**	0.096	−2.446	0.014
$\Delta SEXR_{t-2}^+$	−0.226**	0.090	−2.505	0.012
$\Delta SEXR_{t-3}^+$	−0.211**	0.091	−2.314	0.021
$\Delta SEXR_t^-$	0.742***	0.175	4.228	0.000
$\Delta SEXR_{t-1}^-$	−0.280**	0.179	−1.565	0.118
ECM_{t-1}	−0.018***	0.004	−4.196	0.000
Panel C: NARDL diagnostics				
Diagnostic test			F-statistics	P-values
LM test for autocorrelation			0.183	0.832
Heteroskedasticity ARCH [2]			0.773	0.761
Jarque–Bera for normality			455	<0.01
Ramsey RESET test for model specification			1.838	0.176

Note: *, **, and ***indicate significant at the 10% level, 5% level, and 1% level, respectively.

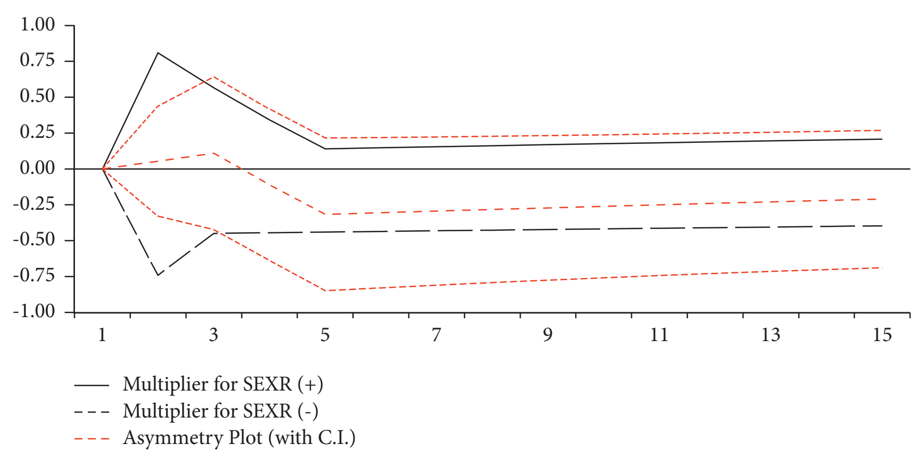

Figure 2: NARDL (1,4,2) dynamic asymmetric multiplier.

the US dollar increases consumer prices by about 0.81% and an appreciation of the Ghana Cedi to the US dollar decreases consumer prices by about 0.74%. The results show very high pass-through during periods of depreciation and appreciation of 81% and 74%, respectively, in the short-run with depreciation topping. The error-correction term indicates a correction of 1.8% of disequilibrium within a month and hence a very low adjustment to the long-run equilibrium.

The higher pass-through of exchange rate depreciation to prices is a confirmation of the stickiness of prices downwards. Depreciation of the cedi means businesses risk losing their working capital. They, therefore, use price hike as the coping strategy against cedi depreciation [33].

Figure 2 shows the dynamic multiplier plot which indicates that a 1% depreciation in the exchange rate increases the short-run consumer prices by more than 0.81% and this converges to about 0.20% in the long-run. Similarly, it is clear that a 1% appreciation of the exchange rate decreases consumer prices by 0.74% in the short-run and this converges to around 0.39% in the long-run.

Panel C of Table 6 shows the NARDL diagnostics which indicate the absence of autocorrelation, Heteroskedasticity, and Ramsey REST test for a model correct specification. The diagnostics generally show that the model is adequate and fit for use.

4. Conclusion

The link between exchange rate and consumer prices have long-standing monetary policy concern for most small open economies. This paper used the EMD-based NARDL model to investigate whether positive and negative changes in the US dollar exchange rates pass through to consumer prices in both the short and long run. The modelling approach adopted eliminates the noisy components of the underlying data to allow us to focus on the core series which matters in monetary policy. Also, a nonlinear and asymmetric relationship can be explored from this framework. Monthly consumer price index and local currency to US dollar exchange rate source from IMF-IFS Database for the period of January 1990 to January 2020 was used.

Our results found cointegration between denoised series of consumer prices and exchange rate and asymmetric pass-through in both the short- and long-run. The exchange pass-through was found to be in the long-run incomplete in the period of depreciation but high, about 53.9%, consistent with the stickiness of prices downwards and statistically zero pass-through in the period of appreciation. In the short-run, the exchange rate pass-through in periods of depreciation is near complete; that is 81% against 74% in periods of appreciation.

These findings have implications for consumers and policymakers. The relatively high exchange pass-through of exchange rate changes to consumer prices suggests that the cost of exchange rate depreciation is borne by consumers. Therefore, persistent exchange rate depreciation may have dire consequences on the individual's consumption pattern, firms' budget planning as well as profitability and corporate tax revenue.

It is therefore imperative that monetary authorities consistently monitor exchange rate behaviour and maintain efficient exchange rate management policies to ensure stable consumer prices. This can be achieved through proper and timely policy interventions using the available monetary policy tools such as foreign exchange reserves. Also, businesses must be encouraged (moral suasion) by the BoG and the banks to patronize forward exchange market facilities (hedging) to reduce the risk of losing their working capital.

Since errors could be introduced in the denoised data, upon which the NARDL was applied, further studies may quantify the extent of errors in a decomposed-based empirical investigation to contribute to prior studies [34–38].

Data Availability

The data used in support of this study is available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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