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Exchange Rate Pass-through in India

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Abstract

Investigating exchange rate fluctuations is important to understand their influence on domestic inflation dynamics of the country as well as to study the stabilisation role played by the monetary policy. Understanding exchange rate pass-through (ERPT) is important especially from emerging markets' perspective since they tend to be net importers. This study examines ERPT for India from 2005Q2 to 2021Q2, i.e., the effects of the nominal effective exchange rate (NEER) on the domestic inflation captured using CPI and WPI. Using linear and non-linear ARDL models, we discover less than perfect exchange rate pass-through for India. The influence is higher for WPI than CPI on account of inelastic crude oil imports. This study also finds a higher influence of exchange rate appreciation than that of depreciation due to the policy measures to limit the pass-through effect of exchange rate depreciation but allowing appreciation to have a complete pass-through.

Keywords: Exchange rate pass-through; ARDL; NARDL; Nominal effective exchange rate; Inflation dynamics.

JEL Code: C32, E31, E32, F31

1. Introduction:

Understanding the dynamics of exchange rate and inflation has been a crucial subject of debate in macroeconomics for a long time. Several exchange rate regimes like (1) fixed exchange rate (Hong Kong, Bahrain, UAE), (2) flexible exchange rate system (US, Euro Area), and (3) managed float (India) tend to influence these dynamics (Mallick and Marques, 2008). The relationship between exchange rate and interest rate also tends to be significantly influenced by the position of an economy on the impossible trilemma/trinity triangle (fixed exchange rate, free capital mobility, independent monetary policy).

This impact of exchange rate fluctuations on domestic inflation dynamics is termed exchange rate pass-through (ERPT). Some of the definitions given in the literature for the exchange rate pass-through are:

"Exchange rate pass-through is the percentage change in the local currency importing countries." – Goldberg and Knetter (1997).

"Exchange rate pass-through is the percentage change in the domestic prices of imported goods following a 1% change between the importing and exporting countries." – Mumtaz *et al.* (2006).

The pass-through is said to be complete if a 1% appreciation (depreciation) in the currency causes an equal amount of decrease (increase) in domestic inflation, and it is incomplete if the inflation changes by a smaller magnitude (Pinshi and Sungani, 2018). It is crucial to assess the pass-through dynamics as it becomes an essential component of the monetary policy-making of the import-dependent countries in particular. As a result, this study chooses India due to its lower import-elasticity (0.60 as per RBI's Report on Currency and Finance, 2022).

Studying ERPT is important as it has the following major macroeconomic implications: (1) it influences the macroeconomic aggregates such as the trade balance, current account balance, investment and GDP (Obstfeld and Rogoff, 2004; Egert and MacDonald, 2009), (2) it highlights the credibility of monetary policy actions (Taylor, 2000; Gagnon and Ihrig, 2004; Aron *et al.,* 2014), (3) it influences the participation in global value chains (Georgiadis *et a.,* 2020). However, the literature on ERPT has been highly skewed toward advanced economies (Campa and Goldberg, 2005; Gopinath *et al.,* 2010; Amiti *et al.,* 2014). However, recent years have seen a growing literature on emerging markets (EM) ERPT on account of various structural changes undertaken in many developing nations like the adoption of inflation

targeting, floating exchange rate regime, easing of capital controls, etc. Also, the high import dependence of the EMs indicates that the pass-through may differ from that of the AEs, forcing them to follow different policies at a domestic level to curb imported inflation (Ghosh and Rajan, 2007).

Quite a few studies focus on the ERPT in India. Mallick and Marques (2008), Dash and Narasimhan (2011), Yanamandra (2015) investigate the pass-through of exchange rate to the import prices whereas the studies examining the pass-through of exchange rates to domestic consumer inflation are limited (Bhattacharya *et al.*, 2008).

Similar to the analysis by Bhattacharya *et al.* (2008), this study investigates the impact of ERPT in India using the consumer price index (CPI) and wholesale price index (WPI) to measure inflation. However, we capture the symmetric and asymmetric effects of the nominal effective exchange rate (NEER) using the linear and non-linear autoregressive distributed lag (ARDL) models. Using quarterly data from 2005Q1 to 2021Q2, we discover a significant pass-through of the exchange rate to the WPI inflation compared to the CPI. This finding seems intuitive given the composition of both indices. While the CPI primarily comprises food prices and services experienced by the consumers, the WPI consists of the manufacturing goods and fuel products. Hence, the majority of imports (which consist of oil and intermediate goods for manufacturing products) directly enter the pricing mechanism of the producers, invariably influencing their price-setting.

Significant ERPT for India can be observed from the import channel to the WPI inflation after accounting for the influence of domestic and global macroeconomic controls like GDP growth rate, imports to GDP ratio, short-term interest rate and global commodity price inflation. All the macroeconomic control variables display significant long-run influence on WPI inflation. On the other hand, only GDP growth rate, short-term interest rate and global commodity price inflation drive WPI inflation in the short-run. Coming to the non-linear effects, appreciation of NEER displays larger effects on WPI than depreciation primarily due to the policy measures like RBI interventaion that limit the pass-through effect of exchange rate depreciation but allow appreciation to have a complete pass-through. Exchange rate overshooting is observed in the short run for WPI as well as CPI (Dornbusch, 1976).

Unlike WPI, CPI responds insignificantly to the movements in NEER. However, in the short run ERPT to the CPI inflation improves when WPI is incorporated as an explanatory variable indicating a clear channel of transmission from exchange rate to WPI to CPI. Short-term

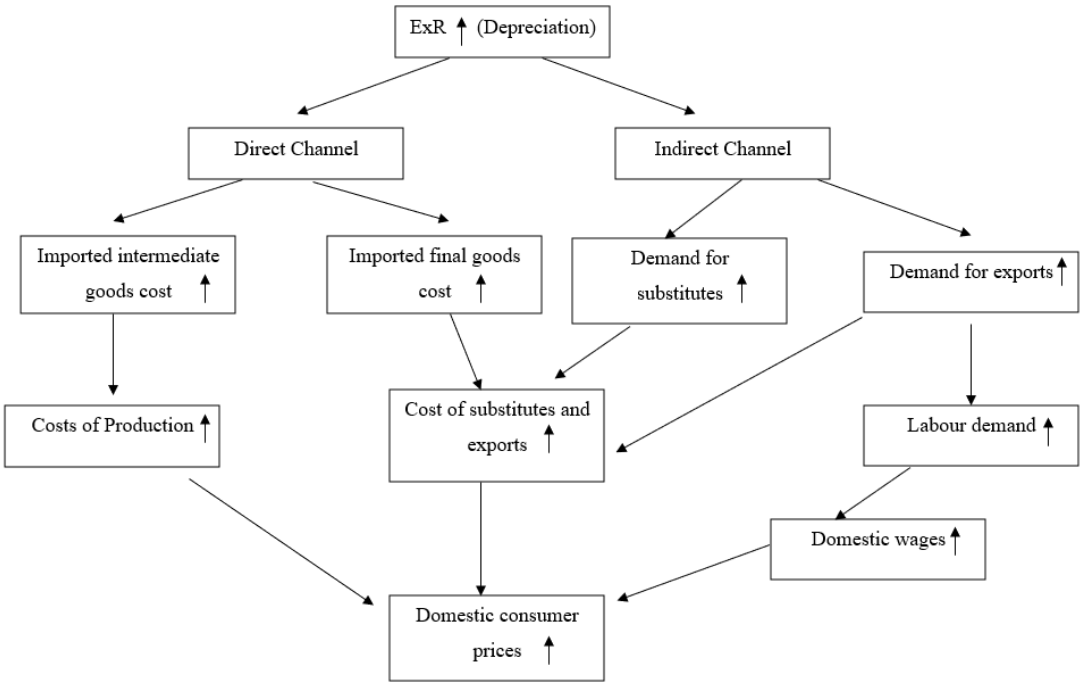
interest rate (WACR) and imports to GDP ratio significantly drive CPI inflation in the long run, whereas NEER, GDP growth rate, WPI inflation and imports to GDP ratio affect CPI inflation in the short run. Results of NARDL analysis for CPI inflation mimic their ARDL results, barring the exchange rate overshooting phenomenon for the positive component of NEER. The positive component of imports to GDP ratio has a larger influence on CPI inflation than the negative one, suggesting significant non-linearities in the transmission of import price inflation to the domestic consumer prices.

The rest of the paper is divided as follows: Section 2 explains various channels of ERPT. Section 3 provides details on the data and descriptive statistics. The methodology used for the analysis is explained in Section 4, while Section 5 details the results. The scope of further research is provided in Section 6 and the Discussions and Conclusions are given in Section 7 and Section 8, respectively.

2. Channels of Exchange Rate Pass-through:

There are two main channels of ERPT from the exchange rates to the inflation: the direct channel and the indirect channel (Lafleche, 1996; Pinshi and Sungani, 2018). A graphical representation of the channels of ERPT is given below.

Figure 1 – Channels of Exchange rate pass-through



Source: Adapted from Lafleche (1996)

2.1 Direct Channel of ERPT:

The exchange rate can influence domestic inflation through the inputs of intermediate and finished goods, and this adds pressure on the firm's balance sheets by increasing capital expenditure and marginal costs of production. The producers then pass on the rise in the prices to the consumers, translating it into a domestic price rise.

2.2 Indirect channel:

The indirect channel of ERPT works through the non-residents' investments and exports. An exchange rate depreciation leads to lower prices of domestic goods for non-residents. This increases exports, and in turn, the aggregate demand, and higher aggregate demand translates itself into inflated domestic prices. High domestic inflation can give rise to a wage-price spiral by increasing the labour demand, putting additional pressure on domestic prices.

3. Data:

This study estimates the exchange rate pass-through for India through the direct channel. The variables used for analysis are provided in the table below:

Table 1 – Variable description and source

Variable representation	Variable name	Source
π^{CPI}	CPI Inflation	FRED
π^{WPI}	WPI Inflation	FRED
$NEER$	Nominal effective exchange rate	RBI DBIE
M/Y	Imports to GDP ratio	FRED
y^{gr}	Real GDP growth rate	FRED
π^{comm}	Global commodity price inflation	FRED
$WACR$	Weighted Average Call Money Rate	RBI DBIE

This study uses two indices to capture inflation: (1) CPI – the prices faced by the consumers, and (2) WPI - the prices faced by the producers. The composition of both baskets varies significantly in the Indian context. While the CPI basket constitutes 45.8% of food products, the share of manufactured products in WPI is 64.2%. NEER is a commonly used measure of the exchange rate in the literature when estimating exchange rate pass-through (Ghosh and Rajan, 2007; Ca'Zorzi *et al.*, 2007, Bhattacharya *et al.*, 2008; Ha *et al*., 2020). It is a weighted basket of the various exchange rates of the countries with whom India has significant trade relations. Imports to GDP ratio constitutes an essential variable for the import channel, which transmits the effects of the exchange rate to domestic inflation. This variable becomes crucial

for a country like India, where the imports are inelastic and mainly comprise commodities like oil, subject to significant fluctuations. GDP growth rate captures the domestic demand-side effects, while the monetary policy influence can be observed from the weighted average call money rate (WACR).

The analysis is conducted quarterly from 2005Q2 to 2021Q2 using 65 observations. The time frame is thus chosen based on the data availability. NEER is available at the 2004-05 base prices from June 2004 to August 2021 on the RBI website. The dataset is thus chosen to avoid any issues that may arise due to splicing a dataset to a new base year. The quarterly analysis is conducted to incorporate the effects of imports to GDP ratio and GDP growth rate. Although many studies use the index of industrial production (IIP) as a proxy for GDP, it does not capture the demand-side effects in its entirety. The datasets are mainly retrieved from the RBI Database on Indian Economy (DBIE) and Federal Reserve Economic Database (FRED). The growth rate for GDP, commodity prices, domestic prices and NEER is estimated year-on-year, while the WACR and imports to GDP ratio are provided in percentage form. The year-on-year growth rate as against the month-on-month or quarter-on-quarter one signifies smoother series and lower volatility, reducing the incidence of heteroscedasticity.

Simple correlations among the variables used for analysis are provided in the table below. The variables of interest inflation and exchange rate display a negative contemporaneous relationship indicating that an exchange rate depreciation is associated with higher inflation.

Table 2 – Correlation among variables used for analysis

	Commodity price inflation	Imports/GDP	GDP growth rate	CPI Inflation	WPI Inflation	NEER growth rate	WACR
Commodity price inflation	1.00						
Imports/GDP	0.20	1.00					
GDP growth rate	0.30	0.25	1.00				
CPI Inflation	-0.10	0.53	0.08	1.00			
WPI Inflation	0.45	0.63	0.35	0.41	1.00		
NEER growth rate	0.27	-0.39	0.32	-0.31	-0.28	1.00	
WACR	-0.16	0.47	0.20	0.07	0.21	-0.30	1.00

Source: Author's estimates

4. Methodology:

The autoregressive distributed lags (ARDL) technique is used to analyze India's exchange rate pass-through. The ARDL model is chosen based on the stationarity results obtained using the Augmented Dickey-Fuller (ADF) unit root tests.

4.1 Augmented Dickey-Fuller Test:

Consider a simple autoregressive process AR (1).

$$y_t = \rho y_{t-1} + X_t'\gamma + \varepsilon_t \quad (1)$$

Where y_t is a data-generating process, and X_t' is a set of optional regressors in the form of either constant or a trend or both. $|\rho| \geq 1$ indicates that the series is non-stationary as the variance of the data-generating process increases with time. $|\rho| < 1$ indicates y to be a trend-stationary process. The stationarity equation is estimated by subtracting y_{t-1} from both the sides of the equation (2).

$$\Delta y_t = \delta y_{t-1} + X_t'\gamma + \varepsilon_t \quad (2)$$

Where $\delta = \rho - 1$. The null hypothesis of this equation ($\delta = 0$) indicates that the variable is non-stationary while the alternative hypothesis ($\delta < 0$) suggests that the variable is stationary.

Table 3 provides the ADF test results indicating that inflation (both WPI and CPI), imports to GDP ratio and WACR are non-stationary, while commodity price inflation, GDP growth rate and NEER growth rate are stationary at a 5 % level of significance.

Table 3 – Unit root tests

	ADF test - Null Hypothesis (Time Series is non-stationary)						
Lags	Commodity price inflation	Imports /GDP	GDP growth rate	CPI Inflation	WPI Inflation	NEER growth rate	WACR
1	**0.03****	0.55	**0.02****	0.45	0.31	**0.01*****	0.23
2	**0.01*****	0.55	**0.08***	0.46	0.25	**0.01*****	0.37
3	**0.01*****	0.56	**0.1***	0.44	0.21	**0.01*****	0.40
4	**0.01*****	0.55	**0.06***	0.41	0.24	**0.01*****	0.40

Notes: *, **, *** represent 10%, 5% and 1% levels of significance respectively, p-values provided here.
Source: Author's estimates

4.2 ARDL Bounds Test:

The vector autoregression model requires all the variables to be stationary.[1] Hence, this study incorporates the ARDL bounds testing approach proposed by Pesaran *et al.* (1999). Using ARDL models gives flexibility with regards to the stationarity of explanatory variables as they can either be I(1) or I(0) or even fractionally integrated (Pesaran (1997)). Further, the cointegration framework allows for the estimation of short-run and long-run effects of the

[1] Non-stationary and stationary variables can be used in a VAR/SVAR model according to Sims *et al*. (1990). It may lead to the loss of efficiency of the estimators but not their consistency.

control variables as each of the underlying variables stands as a single long-run relationship equation[2].

The model used is given as:

$$\Delta\pi_t = \theta_0 + \sum_{j=1}^{L_1}\theta_{1j}\Delta\pi_{t-j} + \sum_{j=0}^{L_2}\theta_{2j}\Delta NEER_{t-j} + \sum_{j=0}^{L_3}\theta_{3j}\Delta WACR_{t-j} + \sum_{j=0}^{L_4}\theta_{4j}\Delta y_{t-j}^{gr} + \sum_{j=0}^{L_5}\theta_{5j}\Delta(M/Y)_{t-j} + \sum_{j=0}^{L_6}\theta_{6j}\Delta\pi_{t-j}^{comm} + \phi_1\pi_{t-1} + \phi_2 NEER_{t-1} + \phi_3 WACR_{t-1} + \phi_4 y_{t-1}^{gr} + \phi_5(M/Y)_{t-1} + \phi_6\pi_{t-1}^{comm} + \varepsilon_t \quad (3)$$

Where $\theta_{ij}'s$ and $\phi_i's$ are short-run and long-run coefficients of the model, respectively. The long-run cointegration is tested using the bounds test. The F-statistic for long-run cointegration is analyzed for the null of $H_0: \phi_1 = \phi_2 = \phi_3 = \phi_4 = \phi_5 = \phi_6 = \phi_7 = 0$ against the alternative hypothesis of H_1: At least one of the $\phi_i's \neq 0$. It gives two values of F-statistics, one where it assumes all the explanatory variables to be I(0) and another when all the variables are assumed to be I(1). The optimal lag lengths are chosen using Akaike Information Criterion (AIC). We test for short-run error correction if the variables are found co-integrated in the long run. The following equation is used for error correction mechanism analysis:

$$\Delta\pi_t = \theta_0 + \sum_{j=1}^{L_1}\theta_{1j}\Delta\pi_{t-j} + \sum_{j=0}^{L_2}\theta_{2j}\Delta NEER_{t-j} + \sum_{j=0}^{L_3}\theta_{3j}\Delta WACR_{t-j} + \sum_{j=0}^{L_4}\theta_{4j}\Delta y_{t-j}^{gr} + \sum_{j=0}^{L_5}\theta_{5j}\Delta(M/Y)_{t-j} + \sum_{j=0}^{L_6}\theta_{6j}\Delta\pi_{t-j}^{comm} + \delta ECM_{t-1} + \varepsilon_t \quad (4)$$

Where δ is the coefficient of the short-term error correction. It shows the speed of reversion of the deviations in the dependent variable on the equilibrium path.

4.3 NARDL Bounds test:

The ARDL model captures linear effects of exchange rate pass-through (ERPT) and other macroeconomic determinants on domestic inflation. But, over the years, the influence of certain variables on inflation would have been non-linear in nature. Some techniques developed in the literature to tackle non-linear error correction mechanisms are Balke and Fomby (1997), Psaradakis *et al*. (2004), Kapetanios et al (2006) and Shin *et al.* (2014). According to Lahiani *et al*. (2016) and Ghosh and Parab (2021), NARDL has three advantages over its linear counterparts: (1) It distinguishes between short- and long-run asymmetries. (2) It captures the response of the dependent variable to positive and negative changes in each explanatory

[2]Once the co-integrating vector is identified, the ARDL model of the co-integrating vector is re-parameterized into an error correction model which gives the short-run dynamics and the long-run relationship of the variables of the model (Nkoro and Uko, 2016).

variable. (3) It is flexible to the co-integration dynamics between variables and it can accommodate multiple data series of different integration orders. This study uses the NARDL model developed by Shin *et al.* (2014). This model captures non-linear short- and long-run asymmetries. It also enables the detection of hidden co-integration, a concept introduced by Granger and Yoon (2002). Hidden co-integration states that the variables may not be linearly correlated but their positive and negative components could be co-integrated with their respective counterparts. The NARDL approach is not applicable for the variables with the integration of order I(2). The following NARDL specification is used for the current analysis:

$$\Delta\pi_t = \theta_0 + \sum_{j=1}^{L_1}\theta_{1j}\Delta\pi_{t-j} + \sum_{j=0}^{L_2}\theta_{2j}^{+}\Delta NEER_{t-j}^{+} + \sum_{j=0}^{L_2'}\theta_{2j}^{-}\Delta NEER_{t-j}^{-} + \sum_{j=0}^{L_3}\theta_{3j}^{+}\Delta WACR_{t-j}^{+} + \sum_{j=0}^{L_3'}\theta_{3j}^{-}\Delta WACR_{t-j}^{-} + \sum_{j=0}^{L_4}\theta_{4j}^{+}\Delta y^{gr+}_{t-j} + \sum_{j=0}^{L_4'}\theta_{4j}^{-}\Delta y^{gr-}_{t-j} + \sum_{j=0}^{L_5}\theta_{5j}^{+}\Delta(M/Y)_{t-j}^{+} + \sum_{j=0}^{L_5'}\theta_{5j}^{-}\Delta(M/Y)_{t-j}^{-} + \sum_{j=0}^{L_6}\theta_{6j}^{+}\Delta\pi_{t-j}^{comm+} + \sum_{j=0}^{L_6'}\theta_{6j}^{-}\Delta\pi_{t-j}^{comm-} + \phi_1\pi_{t-1} + \phi_2^{+}NEER_{t-1}^{+} + \phi_2^{-}NEER_{t-1}^{-} + \phi_3^{+}WACR_{t-1}^{+} + \phi_3^{-}WACR_{t-1}^{-} + \phi_4^{+}y^{gr+}_{t-1} + \phi_4^{-}y^{gr-}_{t-1} + \phi_5^{+}(M/Y)_{t-1}^{+} + \phi_5^{-}(M/Y)_{t-1}^{-} + \phi_6^{+}\pi_{t-1}^{comm+} + \phi_6^{-}\pi_{t-1}^{comm-} + \varepsilon_t \quad (5)$$

where

$$\pi_t = \alpha_1 + \alpha_2^{+}NEER_t^{+} + \alpha_2^{-}NEER_t^{-} + \alpha_3^{+}WACR_t^{+} + \alpha_3^{-}WACR_t^{-} + \alpha_4^{+}y^{gr+}_{t} + \alpha_4^{-}y^{gr-}_{t} + \alpha_5^{+}(M/Y)_t^{+} + \alpha_5^{-}(M/Y)_t^{-} + \alpha_6^{+}\pi_t^{comm+} + \alpha_6^{-}\pi_t^{comm-} + \eta_t \quad (6)$$

η_t is a zero mean stationary error term for the long-run asymmetric relationship between inflation and its determinants. Here, $\alpha_i^{+\prime}s,\ \alpha_i^{-\prime}s$ are long-run asymmetric coefficients of the explanatory variables. For instance, if x_t is an explanatory variable, then its long-run asymmetric components are given by $x_t = x_0 + x_t^{+} + x_t^{-}$. x_0 is an arbitrary initial value and x_t^{+} and x_t^{-} are partial sums of cumulative positive and negative changes, respectively. These partial sum processes are defined as follows:

$$x_t^{+} = \sum_{n=1}^{N}\Delta x_n^{+} = \sum_{n=1}^{N} max(0, \Delta x_n) \quad (7)$$

$$x_t^{-} = \sum_{n=1}^{N}\Delta x_n^{-} = \sum_{n=1}^{N} min(0, \Delta x_n) \quad (8)$$

The values of ϕ_i^{+} and ϕ_i^{-} are given by $\phi_i^{+} = -\phi_1\alpha_i^{+}$ and $\phi_i^{-} = -\phi_1\alpha_i^{-}$ and i=2, 3 … 6.

The empirical methodology is carried out as follows: Using linear ARDL and non-linear ARDL methodologies, we check whether the variables are linearly and non-linearly co-integrated. We then analyse the long-run and short-run effects of ERPT on India's domestic inflation, using domestic and foreign macroeconomic aggregates as control variables. Finally, if non-linear co-

integration exists, we also analyse the long-run and the short-run asymmetric effects of the explanatory variables on domestic inflation.

4.4 Post-estimation diagnostic tests:

A range of post-estimation diagnostics are conducted, namely the Ljung-Box Q test for autocorrelation, Ramsey RESET test and CUSUM squared test (for NARDL only) for the stability of parameters, ARCH LM test for heteroscedasticity and Jarque-Berra test for normality of residuals. Significant autocorrelation among the residuals can lead to under-estimating standard error, inflated t-statistics and prediction inefficiency. As with the presence of heteroscedasticity, the errors do not have constant variance and hence the results obtained from the analysis may not be trustworthy. The assumption that the disturbances are normal allows exact inference about the estimates and standard errors of the estimated coefficients. When the normality assumption is not valid (and the other assumptions are), the estimates are still consistent and the central limit theorem allows one to make inferences that are valid in an asymptotic sense (Wooldridge, 2012). Parameter instability indicates a lower predictive power of the estimates and the results cannot be trusted over time.

5. Results and Analysis:

5.1 ARDL Analysis:

The ARDL analysis provides details on the short-run and long-run relationships among the variables. Three types of models are incorporated for every dependent variable (constant, no constant, constant and trend). Every model includes the Bounds F and Bounds t-statistics to test the presence of long-run co-integrating relationships among the variables. Table 4 below gives the results of the exchange rate pass-through to the CPI inflation.

The model without the trend or intercept displays better long-run relationships between inflation and its explanatory variables as the bounds tests are significant at a 5% level of significance. In the other two cases, a long-run co-integrating relationship is established at a 10% level of significance. The error correction (ECM) term indicates the speed at which a dependent variable returns to equilibrium after a change in other variables. A negative and significant value of the ECM term between 0 and 1 indicates that the short-run dynamics are

stable and the dependent variable reverts to the long-run average. All three types of models in Table 4 indicate a significant convergence speed (around 60%) of CPI inflation to the long-run average.

Table 4 – ARDL model of CPI Inflation

Long-run			
Variable	**(1)**	**(2)**	**(3)**
ECM term	**-0.62*** **	**-0.58*** **	**-0.67*** **
(Intercept)	-1.98		0.37
Trend CPI			-0.02
NEER	-0.07	-0.15	-0.08
WACR	**-1.35*** **	**-1.41*** **	**-1.29*** **
GDP Growth	0.11	0.16	0.05
M/Y	**0.84*** **	0.74	**0.76*** **
Comm Inf	-0.06	-0.07*	-0.06
Short-run			
(Intercept)	-1.24		0.25
Trend CPI			-0.02
L(CPI Inflation, 1)	**0.56*** **	**0.58*** **	**0.51*** **
L(CPI Inflation, 2)	-0.04	-0.03	-0.06
L(CPI Inflation, 3)	0.21	0.2	0.23
L(CPI Inflation, 4)	**-0.36** **	**-0.34** **	**-0.35** **
NEER	-0.04	-0.06	-0.04
L(NEER, 1)	0.06	0.06	0.06
L(NEER, 2)	-0.05	-0.05	-0.05
L(NEER, 3)	0.02	0.02	0.02
L(NEER, 4)	-0.03	-0.06	-0.04
WACR	-0.18	-0.17	-0.16
L(WACR, 1)	-0.07	-0.07	-0.07
L(WACR, 2)	-0.15	-0.14	-0.16
L(WACR, 3)	**-0.23***	**-0.22***	**-0.24***
L(WACR, 4)	-0.21	**-0.22***	**-0.23***
GDP growth	-0.01	0.00	-0.02
L(GDP growth, 1)	-0.02	-0.02	-0.03
L(GDP growth, 2)	0.03	0.04	0.02
L(GDP growth, 3)	0.01	0.01	0.00
L(GDP growth, 4)	0.07	0.07	0.06
M/Y	0.17	0.21	0.14
L(M/Y, 1)	-0.16	-0.18	-0.17
L(M/Y, 2)	**0.51** **	**0.49*** **	**0.50*** **
L(M/Y, 3)	0.01	-0.02	0.01
L(M/Y, 4)	-0.01	-0.07	0.02
Comm Inf	-0.02	-0.02	-0.02
L(Comm Inf, 1)	0.03	0.03	0.04
L(Comm Inf, 2)	-0.02	-0.02	-0.02
L(Comm Inf, 3)	**-0.06***	**-0.06***	**-0.06***
L(Comm Inf, 4)	0.02	0.03	0.02
Diagnostic tests			
Bounds F-test	**0.05***	**0.02** **	**0.07***
Bounds t-test	**0.07***	**0.03** **	**0.1***
Jarque-Berra test	0.9	0.81	0.29
Ljung-Box Q	0.78	0.69	0.77
Arch LM	0.45	0.19	0.42
RESET	0.3	0.97	0.33

Notes: *, **, *** represent 10%, 5% and 1% levels of significance respectively. Columns (1), (2) and (3) give the results of the ARDL equations with constant, no constant, with constant and trend, respectively. The lag structure for this model is (4,4,4,4,4,4).
Source: Author's estimates

The results indicate an incomplete pass-through of the exchange rate to inflation. Though the signs are in line with the theory (a negative sign suggests that the exchange rate depreciation increases inflation), CPI inflation is not influenced significantly by the exchange rate in the long run. Monetary policy and imports to GDP have a significant long-run influence on inflation with the desired signs. A higher interest rate leads to lesser borrowing and lesser availability of banking credit, decreasing aggregate demand and, finally, inflation. Higher imports indicate that the domestic prices increase as a significant proportion of India's imports is inelastic in the form of oil and other commodities.

The post-estimation diagnostics indicate the absence of heteroscedasticity and autocorrelation in the errors. The Ramsey RESET test suggests that the parameters are correctly specified and the Jarque-Berra test results show that the residuals are normally distributed.

As with the short-run effects, inflation is significantly driven by its own first lag, indicating stickiness in the prices. The exchange rate pass-through is around 5% to the CPI inflation, albeit insignificant. WACR has a lagged influence on inflation over 3 to 4 quarters. Imports/GDP ratio display significant short-run effects over six months. On the whole, though the exchange rate pass-through is incomplete in the Indian context, higher imports and the subsequent monetary policy measures significantly influence CPI inflation.

Considering WPI-based inflation as an explanatory variable displays significant exchange rate pass-through (Table 5). Negative and significant ECM term between 0 and 1 suggests significant convergence (>65%) of WPI inflation to its long-run average. Significant long-run effects can be observed for all the variables can be observed with the desired sign. Despite being significant, the pass-through of NEER to the WPI inflation is still incomplete (20%). However, unlike in the case of CPI, the demand-side variables and global commodity price inflation significantly influence the movements in domestic inflation.

With regards to the short-run effects, WPI inflation is not as persistent as CPI, with its first lag having an insignificant impact with a coefficient of 0.15. The exchange rate pass-through is significant in the short-run as well, with the rupee depreciation leading to an increase in the WPI inflation over two quarters. However, the pass-through averages around 15%. Monetary policy displays significant lagged effects for the 2nd and 3rd quarters, with an increase in the interest rates leading to lower inflation. Demand-side shocks increase inflation in the short-run as well. Unlike their long-run counterparts, the imports to GDP ratio fails to influence the WPI

inflation in the short run significantly. Global commodity prices drive domestic inflation in the short run.

Table 5 – ARDL model of WPI Inflation

Long-run			
Variable	**(1)**	**(2)**	**(3)**
ECM term	**-0.67*** **	**-0.65*** **	**-0.69*** **
(Intercept)	-0.88		1.01
Trend WPI			-0.02
NEER	**-0.18** **	**-0.20*** **	**-0.20** **
WACR	**-1.00*** **	**-1.02*** **	**-0.96*** **
GDP Growth	**0.16*** **	**0.17*** **	**0.14*** **
M/Y	**0.48*** **	**0.44*** **	**0.41*** **
Comm Inf	**0.20*** **	**0.20*** **	**0.20*** **
Short-run			
(Intercept)	-0.59		0.7
Trend WPI			-0.01
L(WPI Inflation, 1)	0.15	**0.16***	0.12
L(WPI Inflation, 2)	0.08	0.08	0.07
L(WPI Inflation, 3)	0.11	0.11	0.11
NEER	-0.03	-0.04	-0.04
L(NEER, 1)	-0.03	-0.03	-0.03
L(NEER, 2)	**-0.15*** **	**-0.14*** **	**-0.15*** **
L(NEER, 3)	-0.02	-0.02	-0.03
L(NEER, 4)	**0.12*** **	**0.11*** **	**0.11** **
WACR	-0.2	**-0.19** **	**-0.19** **
L(WACR, 1)	-0.1	-0.1	-0.09
L(WACR, 2)	**-0.15***	**-0.15***	**-0.15***
L(WACR, 3)	**-0.22** **	**-0.23*** **	**-0.23*** **
GDP growth	**0.11*** **	**0.11*** **	**0.10*** **
M/Y	-0.14	-0.13	-0.16
L(M/Y, 1)	0.01	0.00	0.00
L(M/Y, 2)	0.15	0.14	0.15
L(M/Y, 3)	0.16	0.15	0.16
L(M/Y, 4)	0.14	0.13	0.15
Comm Inf	-0.01	-0.01	-0.01
L(Comm Inf, 1)	**0.14*** **	**0.14*** **	**0.15*** **
Diagnostic tests			
Bounds F-test	**0.00*** **	**0.00*** **	**0.00*** **
Bounds t-test	**0.00*** **	**0.00*** **	**0.00*** **
Jarque-Berra test	0.20	0.16	0.29
Ljung-Box Q	0.75	0.85	0.38
Arch LM	0.42	0.22	0.91
RESET	**0.09***	**0.09***	**0.04** **

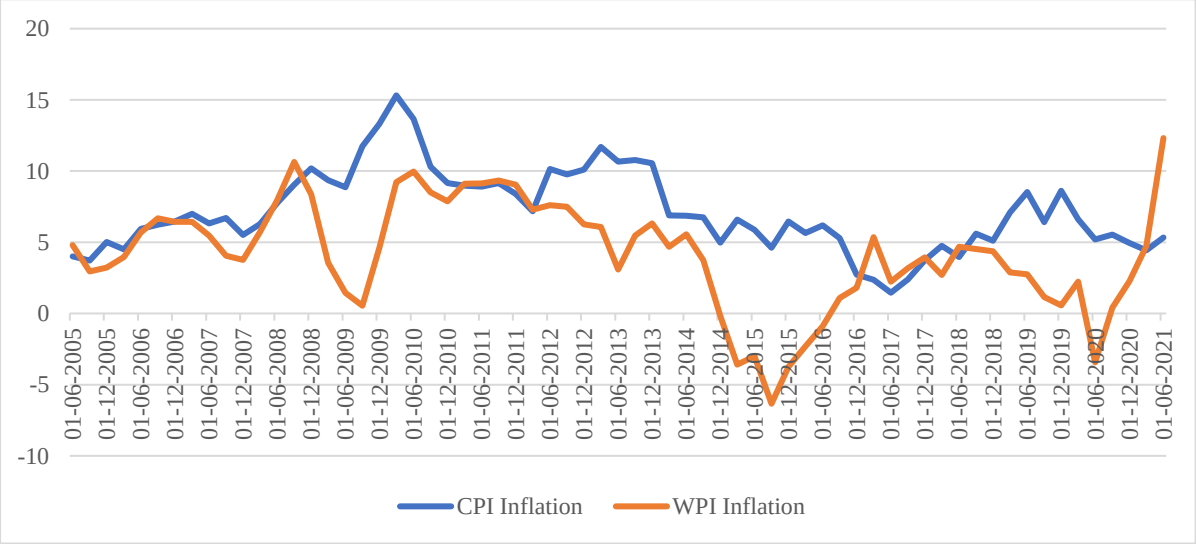
Notes: *, **, *** represent 10%, 5% and 1% levels of significance respectively. Columns (1), (2) and (3) give the results of the ARDL equations with constant, no constant, with constant and trend, respectively. The lag structure of this model is (3,4,3,0,4,1).
Source: Author's estimates

A significant ERPT to the WPI inflation may be due to the composition of the indices. While the CPI primarily comprises food prices and services experienced by the consumers, the WPI consists mainly of the manufacturing goods and fuel products. Hence, the majority of imports (which consist of oil and intermediate goods for manufacturing products) directly enter the

pricing mechanism of the producers, invariably influencing their price-setting. As a result, the pass-through of India's exchange rate can be observed from the import channel to the WPI inflation, with a significant role played by the monetary policy and demand-side factors.

The post-estimation diagnostics show that the residuals are normally distributed and have no autocorrelation and heteroscedasticity. However, the Ramsey RESET test statistics indicate that the equation is not correctly specified. Incorporating interaction terms or non-linear estimation techniques can help to tackle this issue. This study also attempts to check the effects of the pass-through of the WPI inflation to CPI. A simple graphical analysis displays an incomplete pass-through of the WPI inflation to the CPI (correlation coefficient – 0.41 as seen in Table 2). This can also be observed in recent times, where the producers did not pass on the price rises to the final consumers anticipating a demand reduction. A study by Edelweiss in June 2021 supports this finding of incomplete pass-through of WPI inflation to CPI.

Figure 2 – CPI vs. WPI Inflation in India



Source: FRED Statistics

In order to statistically test the effects of the WPI pass-through, this study incorporates WPI as an explanatory variable in the ARDL equation of the CPI. The results are provided in Table 6. Negative and significant ECM term between 0 and 1 suggests significant convergence (>45%) of CPI inflation to its long-run average. The speed of adjustment to the long-run mean reduces when WPI inflation is incorporated as an explanatory variable in the CPI equation.

Table 6 – ARDL model of CPI Inflation (with WPI Inflation as an explanatory variable)

Long-run			
Variable	**(1)**	**(2)**	**(3)**
ECM Term	**-0.45*** **	**-0.45*** **	**-0.47*** **
(Intercept)	1.55		4.05
Trend CPI			-0.03
NEER	-0.16	-0.14	-0.16
WPI Inflation	0.1	0.04	0.02
WACR	**-1.51*** **	**-1.49*** **	**-1.52*** **
GDP Growth	0.21*	0.19	0.15
M/Y	**0.66*** **	**0.74*** **	**0.63*** **
Comm Inf	-0.02	-0.02	-0.02
Short-run			
(Intercept)	0.71		1.91
Trend CPI			-0.02
L(CPI Inflation, 1)	**0.57*** **	**0.58*** **	**0.54*** **
L(CPI Inflation, 2)	0.14	0.13	0.12
L(CPI Inflation, 3)	-0.16	-0.16	-0.14
NEER	0.00	-0.01	0.00
L(NEER, 1)	0.04	0.04	0.04
L(NEER, 2)	**-0.10** **	**-0.10** **	**-0.11** **
WPI Inflation	**0.27** **	**0.27** **	**0.26** **
L(WPI Inflation, 1)	**-0.34** **	**-0.35** **	**-0.35** **
L(WPI Inflation, 2)	**-0.23***	**-0.23***	**-0.23***
L(WPI Inflation, 3)	0.17	0.18	0.17
L(WPI Inflation, 4)	**0.18***	**0.16***	0.16
WACR	-0.13	-0.14	-0.13
L(WACR, 1)	-0.08	-0.08	-0.08
L(WACR, 2)	-0.15	-0.14	-0.16
L(WACR, 3)	-0.17	-0.16	**-0.18***
L(WACR, 4)	-0.16	-0.15	-0.17
GDP growth	0	0	-0.01
L(GDP growth, 1)	-0.01	-0.01	-0.01
L(GDP growth, 2)	**0.10** **	**0.10** **	**0.09***
M/Y	0.11	0.12	0.08
L(M/Y, 1)	-0.2	-0.19	-0.18
L(M/Y, 2)	**0.39*** **	**0.41*** **	**0.40*** **
Comm Inf	-0.01	-0.01	-0.01
Diagnostic tests			
Bounds F-test	**0.00*** **	**0.00*** **	**0.00*** **
Bounds t-test	**0.00*** **	**0.00*** **	**0.00*** **
Jarque-Berra test	0.87	0.82	0.22
Ljung-Box Q	0.12	0.13	**0.08***
Arch LM	**0.02** **	**0.05** **	**0.08***
RESET	0.68	0.60	0.80

Notes: *, **, *** represent 10%, 5% and 1% levels of significance respectively. Columns (1), (2) and (3) give the results of the ARDL equations with constant, no constant, with constant and trend, respectively. The lag structure of this model is (3,2,4,4,2,2,0).
Source: Author's estimates

However, it improves the pass-through of NEER to CPI significantly. In the short run, a depreciation in the exchange rate increases inflation by around 10% over two quarters. WPI inflation significantly affects CPI inflation, albeit with a lower magnitude of about 27%. The demand-side factors, insignificant in Table 4, are statistically significant in the short run over

a 2-quarter horizon. Imports to GDP ratio significantly drive inflation CPI inflation in the short run (over two quarters) as well as in the long run.

The post-estimation diagnostics suggest that the residuals do not display significant non-normality and autocorrelation in most cases. The errors tend to be heteroscedastic for all three types of equations.

5.2 NARDL Analysis:

This study also conducts the NARDL analysis to test the asymmetric effects of ERPT on domestic inflation in India. Table 7 provides the results for the NARDL analysis on the three types of equations used for the analysis: CPI inflation, WPI inflation and CPI inflation with WPI inflation as an explanatory variable. The bounds test indicates the presence of significant long-run asymmetric relationships only when WPI inflation is taken as a dependent variable. A negative and significant value of the ECM term for all three equations suggests that domestic inflation converges significantly to the long-run average. This adjustment speed is the highest for WPI inflation (75%).

The analysis shows the absence of long-run asymmetric effects of all the variables on domestic inflation barring the impact of NEER on WPI inflation. The coefficients of individual determinants indicate that CPI inflation is significantly influenced in the long run by the interest rate and M/Y while NEER, GDP growth rate and global commodity prices influence WPI inflation. The effect of exchange rate appreciation is higher on WPI than that of depreciation. This can be attributed to the policy measures (RBI intervention and exchange rate stabilisation) that limit the pass-through effect of exchange rate depreciation but allow appreciation to have a complete pass-through. Higher GDP growth and increase in global commodity price inflation increase WPI inflation over a longer run.

As for the short-run dynamics, NEER displays significant asymmetric effects on CPI as well as WPI inflation while the imports to GDP ratio affects WPI inflation. In the short run, the exchange rate shows perverse effects on inflation. This can be due to exchange rate overshooting and sticky prices (Dornbusch, 1976). Interest rate reduction displays a significant contemporaneous effect on CPI inflation in the short run. This points out to the asymmetric monetary policy transmission where a reduction in short-term interest rates significantly increases domestic consumer price inflation but the effect is insignificant in the other direction. GDP influences inflation in the short term in the desired direction for both measures. However,

it is only in the case of WPI that both the positive and negative components of GDP drive domestic inflation. The negative component of M/Y has a perverse effect on all three measures of inflation in the short run. Global commodity prices significantly drive CPI inflation in the short run while the effects on WPI inflation are insignificant. The effects of only the positive component are higher in the augmented CPI equation.

The post-estimation diagnostics indicate that the parameters are stable for all the equations (CUSUM squared test[3]). Baseline CPI inflation shows the presence of autocorrelation, heteroscedasticity and measurement errors. The WPI equation satisfies all the post-estimation dynamics deeming it a better index to analyse the pass-through. on the other hand, the error terms of the augmented CPI equation show the presence of autocorrelation.

Table 7 – Non-linear ARDL model for ERPT in India

	(1)	(2)	(3)
Variable	**CPI Inflation**	**WPI Inflation**	**CPI Inflation (Augmented)**
ECM term	**-0.50*** **	**-0.75*** **	**-0.38** **
Long Run			
NEER +	-0.04	**-0.35*** **	0.01
NEER -	-0.06	**-0.23*** **	0.04
WPI Inflation +			0.02
WPI Inflation -			-0.33
WACR +	**-1.28*** **	-0.06	**-1.26** **
WACR -	**-1.01*** **	-0.28	**-1.04** **
GDP growth +	0.06	**0.27** **	-0.15
GDP growth -	0.19	**0.24***	-0.02
M/Y +	**0.82***	-0.26	**1.01** **
M/Y -	0.41	0.01	**0.76***
Comm_Inf +	-0.04	**0.13*** **	-0.07
Comm_Inf -	-0.02	0.06	-0.02
Short Run			
ΔCPI Inflation	-0.10		**-0.26***
ΔWPI Inflation		-0.14	
ΔNEER (t) +	-0.06	-0.05	-0.05
ΔNEER (t-1) +	**0.25** **	**0.28*** **	**0.22***
ΔNEER (t) -	-0.10	**-0.16** **	0.02
ΔNEER (t-1) -	-0.17	-0.01	-0.15
ΔWPI (t) +			-0.29
ΔWPI (t-1) +			0.22
ΔWPI (t) -			0.42
ΔWPI (t-1) -			0.24
ΔWACR (t) +	0.04	0.04	0.11
ΔWACR (t-1) +	0.26	0.32	-0.08
ΔWACR (t) -	**-0.80** **	-0.11	**-0.95*** **
ΔWACR (t-1) -	**0.47** **	0.07	**0.42***
ΔGDP (t) +	-0.02	**0.21** **	-0.03
ΔGDP (t-1) +	0.08	0.04	-0.06
ΔGDP (t) -	**0.10***	**0.12*** **	0.05
ΔGDP (t-1) -	-0.16	-0.05	0.03

[3] The graphs of CUSUM squared tests as well as the dynamic multipliers of the NARDL analysis are available with the authors and can be provided upon request.

ΔM/Y (t) +	**0.53***	0.02	**0.77****
ΔM/Y (t-1) +	-0.49	0.25	-0.59
ΔM/Y (t) -	0.06	-0.20	0.17
ΔM/Y (t-1) -	**-0.78****	**-0.47****	**-0.87*****
ΔComm Inf (t) +	-0.06	-0.04	**-0.09***
ΔComm Inf (t-1) +	**0.07****	-0.03	**0.10****
ΔComm Inf (t) -	0.03	-0.03	0.02
ΔComm_Inf (t-1) -	**0.08***	0.04	0.04
Constant	**2.08****	**2.81*****	1.69
Asymmetry - Long Run			
NEER	0.09	**7.35****	0.09
WPI Inflation			0.48
WACR	0.83	1.13	0.53
GDP Growth	2.18	0.41	1.64
M/Y	0.29	0.21	0.13
Comm Inf	0.08	1.33	0.30
Asymmetry - Short Run			
NEER	**2.96***	**3.25***	1.24
WPI Inflation			1.15
WACR	2.49	1.46	0.92
GDP Growth	0.20	0.68	0.32
M/Y	1.60	**3.81***	1.23
Comm Inf	1.23	1.66	0.38
Diagnostic tests			
Bounds F-test	3.64	**6.24*****	3.63
Bounds t-test	-4.19*	**-6.08*****	-2.29
CUSUM Squared test	Stable	Stable	Stable
Portmanteau test	**0.01****	0.31	**0.02****
J-B normality	0.15	0.30	0.92
B-P Heteroscedasticity	**0.03****	0.21	0.88
Ramsey RESET	**0.06***	0.52	0.19

Notes: *, **, *** represent 10%, 5% and 1% levels of significance respectively. Columns (1), (2) and (3) give the results of the ARDL equations with CPI baseline, WPI and CPI augmented, respectively.
Source: Author's estimates

6. Scope of further research:

This study conducts a linear as well as non-linear ARDL analysis to investigate the effects of ERPT on domestic inflation in India. However, this area has abundant scope for further research. The pass-through can also be analysed in light of major global events like the global financial crisis, taper tantrum, the COVID-19 pandemic, the ensuing lockdowns, and the Russia-Ukraine war using structural dummies obtained from the tests like Zivot-Andrews test, Chow test, Bai-Perron test. Advanced structural models can be used to analyse the same. This study conducts the analysis only using the direct channel of ERPT. The indirect channel study can help draw more insights into the ERPT for India. However, this study might be difficult to conduct because of the lack of data availability for the variables like labour demand, aggregate wages and prices of substitute goods.

7. Discussions:

The study of exchange rate pass-through has become crucial for a country like India in the recent context due to the global developments like the onslaught of COVID-19 and the subsequent supply-chain disruptions; the Russia-Ukraine war that created ripples across the global trade and volatility among global macroeconomic indicators. An increase in the prices of the major commodities that India imports, like crude oil and palm oil, accompanied by the rupee depreciation against the US Dollar (lifetime low of 80.6), has led to the inflation being generalized and is likely to continue if the after-effects of the war are not contained. In addition, India's domestic crude oil production was at a 28-year low, at 28.4 million tonnes in 2021-22. India is the third-largest importer of crude oil in the world, behind only China and the US. A significant pass-through of the exchange rate from the inelastic imports to the producer prices and, in turn, to the consumer prices indicates that domestic inflation is likely to remain elevated in India over the next year. Short-term stabilisation of the exchange rate as is carried out by the RBI can help to mitigate the effects of imported inflation.

8. Conclusions:

This study investigates the linear and non-linear exchange rate pass-through to inflation in India for over 16 years. This analysis is conducted using linear and non-linear ARDL models. For the analysis conducted from 2005Q1 to 2021Q2, we discover a significant pass-through of the exchange rate to the inflation, primarily WPI inflation. Given that India is an emerging market and a net importer, the influence of exchange rate (captured using NEER) on WPI inflation makes intuitive sense. CPI is primarily composed of food prices and services experienced by the consumers. On the other hand, WPI comprises of the manufacturing goods and fuel products. Hence, a significantly large proportion of imports directly enter the pricing mechanism of the producers, influencing their price-setting.

Using domestic and global variables as macroeconomic controls, significant ERPT for India can be observed from the import channel to the WPI inflation. All the other macroeconomic controls (interest rate, GDP growth rate, imports to GDP ratio and global commodity price inflation) have a significant long-run influence on WPI inflation. On the other hand, imports to GDP ratio fails to have significant short-run effects on WPI inflation. As for the non-linear effects, appreciation of NEER displays larger effects on WPI than depreciation. This can be

attributed to the policy measures (RBI intervention and exchange rate stabilisation) that limit the pass-through effect of exchange rate depreciation but allow appreciation to have a complete pass-through. In the short run, the exchange rate shows perverse effects on WPI inflation owing to exchange rate overshooting and sticky prices (Dornbusch, 1976).

Unlike WPI, CPI responds insignificantly to the movements in NEER. However, the short-run pass-through improves when WPI is incorporated as an explanatory variable in the CPI equation. This indicates a clear channel of transmission from exchange rate to WPI to CPI. However, this pass-through is incomplete as the producers do not pass-on complete effects of imported inflation on to the consumers. With regards to the controls, only short-term interest rate (WACR) and imports to GDP ratio significantly drive CPI inflation in the long run. NEER, GDP growth rate, WPI inflation and imports to GDP ratio affect CPI inflation in the short run. CPI inflation is more persistent than WPI inflation. Results of NARDL analysis for CPI inflation mimic their ARDL results. An increase in imports to GDP ratio has a larger influence on CPI inflation than the decline, indicating significant non-linearities in the transmission of import price inflation to the domestic consumer prices.

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