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An examination of the pass-through of disaggregated energy prices to real house price: Evidence from the United States

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Our study investigates the dynamic pass-through of energy prices (crude oil price, electricity price, natural gas price, and coal price) to real house price in the United States using the data from 1970 to 2017. Based on the autoregressive distributed lag (ARDL) model, the empirical results suggest an incomplete pass-through for all the energy prices to real house price both in the long run and short run except for long-run pass-through of crude oil price which is complete with statistically insignificant parameter. The Granger causality results reveal a feedback effect between natural gas price and real house price, output growth and real house price, natural gas price and crude oil price, coal price and electricity price, and output growth and coal price. In addition, a unidirectional causal relationship is found running from crude oil price, natural gas price, real house price, and coal price to electricity price. Again, we find that crude oil price is the cause of coal price in Granger sense. Therefore, our findings provide insights into proper design of energy policy that reduces the transmission of energy price shocks to house price in the United States.

KEYWORDS
ARDL, cointegration, energy prices, real house price, United States

1 | INTRODUCTION

The importance of understanding the pass-through of energy prices to house prices especially in the United States cannot be more crucial and timelier. This is not only because of the relevance of the study to stakeholders in the energy sector but it is advantageous to optimal hedging issue and the management of portfolio risk. Generally, the sources of energy include the renewable (solar, geothermal, wind, biomass, and hydropower) and non-renewable (petroleum products, hydrocarbon gas liquids, natural gas, coal and nuclear energy) (Energy International Agency [EIA], 2018). The prices of these energy sources are not only important to the oil exporting and importing countries, it consequentially determines the dynamics of the global economies. For instance, the significance of crude oil, which is the most utilized energy source (EIA, 2018), accounts for why the real oil price is important to the marketing structure of the economy and the policymakers. Like the crude oil price, energy prices generally and significantly determine the consumers and producers' priority planning, decision, direction, and project evaluation. This is mostly because of the relationship between the crude oil price (the main energy source) and the energy prices, which has been widely acknowledged in the extant literature (Borenstein et al., 1997; Asche et al., 2006; Ozturk, 2010; Lahiani et al., 2017; Bekun, Alola, & Sarkodie, 2019). This seemingly overbearing impact of energy prices on the global economy causes erratic price movement, which is a potent factor that determines investor decisions. Moreover, the fact that asset prices are also calculated by using a model for discounted cash flows, which remarkably sums up the expected future discounted cash flows, a shock on energy prices apparently affects either the cash flows expected or the rate of discount in the asset pricing model (Benkraiem et al., 2018).

In addition, the significance of the global dynamics of energy prices suggests that the energy market is not immune to the event(s) from other market forces. For instance, the house market or real estate market is another important global market especially in the United States. An illustration is the Global Financial Crisis (GFC) or the Great Recession, which started in 2008 in the United States and affected millions of Americans and other world economies. The GFC is acknowledged to have started from the U.S. Subprime Mortgage sector and subsequently spiraled to other sectors of the U.S. economy, including the energy sector. As opined, there was an "*expansion of mortgages to high-risk borrowers, coupled with rising house prices, contributed to a period of turmoil in financial markets that lasted from 2007 to 2010*" (US Federal Reserve Bank, 2018). The relationship between energy prices and house price is more evidence in the United States. This is because about 20% of primary energy consumed in the United States is in the residential sector. In general, 97.7 quadrillion Btu of the total U.S. primary energy consumption is shared among the end-use sectors of industrial (32%), transportation (29%), residential (20%), and commercial (18%) (EIA, 2018). But the energy and environmental policies introduced and adopted in most advanced economies to mitigate the effect of climate change have further complicated the dynamics of energy-house prices (Alola, 2018). Hence, the introduction of a wide range of energy monitoring instruments and environmental labels to both the commercial and the residential sectors of the real estate market has raised more research questions.

Therefore, the current study builds on the aforementioned motivation to extend the literature of energy-house prices nexus especially in the light of attaining highly energy efficient or zero carbon buildings. As such, we examine the pass-through of energy prices to real house price in the United States over the period 1970–2017 by using a flexible autoregressive-distributed lag (ARDL) estimation approach. Hence, this study is designed to potentially add novelty to the literature based on the following:

- First, by decomposing energy price aggregate, the study uniquely examines the possibility of a stable long-run connection between disaggregated energy prices such as crude oil price, electricity price, natural gas price, and coal price and real house price using the ARDL bounds testing methodology proposed by Pesaran, Shin, and Smith (Pesaran et al., 2001).
- Second, in addition to examining the long-run nexus, the long- and short-run pass-through coefficients are obtained through ARDL models. We also applied a Wald test statistic to determine whether the pass-through is complete or incomplete along the house price chains.
- Lastly, the Granger causality test based on the block exogeneity Wald tests is conducted to determine the directional causality between investigated variables.

The rest of the sections are organized as follows. Section 2 is a brief literature review related to this study. The data and methodology are presented in Section 3. The results of the study are discussed in Section 4, while Section 5 presents concluding remarks that incorporate policy implications for the study and proposal for future study.

2 | THEORETICAL FRAMEWORK AND BRIEF LITERATURE OVERVIEW

The theoretical framework in the literature of pass-through is rested on the doctrine of purchasing power parity (PPP), which is an offshoot of the law of one price (See Balcilar et al., 2019; Balcilar, Roubaud, et al., 2020; Balcilar, Usman, & Musa, 2020; Usman, 2020; Usman, Iorember, & Jelilov, 2020; Usman, Iorember, & Uzuner, 2020). According to this doctrine as originally propounded by Cassel (1916) is that tradable goods and services are equal in different countries if prices are expressed using the same unit of currency. Applying this doctrine, therefore, indicates that the pass-through of energy prices to real house price is expected to be complete (i.e., one-to-one pass-through) if their prices are in the same currency. This assumption is basically hinged on the fact that there is no existence of transportation costs, tariffs, imperfect competition, and other trade barriers.

In spite of the dynamics in the energy sector resulting from the energy portfolio diversification, energy and oil prices have continued to relatively dictate the dynamics of the global economies. Recently, the energy prices have been studied with statistical evidence revealing their pass-through to other financial market components (Alola et al., 2019; Apergis & Vouzavalis, 2018; Atil et al., 2014; Bekun, Emir, & Sarkodie, 2019; Benkraiem et al., 2018; Borenstein et al., 1997; Emir & Bekun, 2019; Ike et al., 2020; Lahiani et al., 2017). Specifically, Li et al. (2018) examined the transmission of energy prices to fluid milk products at the retail level in 12 U.S. cities over the period 2001–2011. In doing so, the study affirms the statistical evidence of an asymmetric energy price pass-through to milk products except for the low response from the private label milk products. The study reveals that the private label milk products thus adjust to a similar rate with national manufacturer brands in spite of its lower response from the energy price shock.

In a similar approach, while investigating the pass-through of energy prices to the U.S. manufacturing sector, Ganapati et al. (2016) found that the marginal costs pass-through is incomplete since the estimate is centered about 0.7. As such, with statistical evidence, the confidence intervals of the estimate reject both zero pass-through and complete pass-through. Again, Clark and Terry (2010) explore the Bayesian approach of a vector autoregressive model to investigate the time variation in the inflation pass-through of energy prices. The result found that there is a significant fall in the responsiveness of core inflation to changes in energy prices in the United States at least in 1975. This was observed to be significantly passive during the period of higher volatility of shocks to energy inflation and the deployment of monetary policy.

Moreover, in addition to studying the energy prices pass-through to other market products, previous studies have equally examined intra pass-through of energy prices. For instance, Atil et al. (2014) carefully examined the asymmetric pass-through of crude oil prices to gasoline and natural gas prices. The result of the investigation indicates that oil prices affect gasoline prices and natural gas prices, thus revealing an uneven price transmission mechanism. In a recent study by Lahiani et al. (2017), who employed the Quantile Autoregressive Distributed Lags (QARDL), it examined the nexus of oil prices and energy prices in the United States. The result of the investigation indicates that the pass-through of oil prices to a set of energy prices is statistically significant; hence, the components of energy prices reveal cointegration with oil prices across the quantiles.

Based on the available literature reviewed, it is observed that even though the attention of the globe has been directed toward revitalizing energy sector as a mover of world economy in the 21st century, no study has notably investigated the dynamic effects of energy prices on real house price based on disaggregated data. We do hope that the findings of this study would help in the designing energy policy instruments regarding the transmission of energy prices to house prices in the United States.

3 | DATA AND RESEARCH METHODOLOGY

3.1 | Data

This investigates the disaggregated prices of energy (crude oil, electricity, natural gas, coal prices) through to real house price in the United States from 1970 to 2017. We incorporate output growth as a control variable. The real house price is measured as the proportion of nominal house price to the expenditure of consumer deflator in the United States (2015 = 100). The energy prices are measured as follows: Crude oil price is measured as the domestic first purchase price expressed in U.S. dollars per barrel. Electricity price used is the average retail price of electricity, industries in U.S. cents per kilowatt-hour, including taxes. The natural gas price delivered to consumers, industries in U.S. dollars per thousand cubic feet is used, while the coal price is measured as the nominal coal price (dollars per short ton). To explore the nominal coal price in our estimation, we adjust it for inflation by dividing nominal coal price by inflation. Finally, we measured output growth as the industrial production index of mining, manufacturing, electricity, gas and steam and air-conditioning sectors in the United States (2015 = 100) adjusted seasonally. All the energy prices are obtained from the U.S. Energy EIA (2018), while real house price and industrial production index are obtained from the database of OECD, 2018.

3.2 | Unit root tests

To check stochastic properties of variables, we apply two distinct tests, which include Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The null hypothesis for ADF and PP is that $H_0 : \rho = 0$ while alternative one simply states that $H_1 : \rho < 0$.

3.3 | ARDL bounds testing approach

To achieve the study's objective, the functional relationship between real house price, crude oil price, electricity price, natural gas price, coal price and output growth in the U.S. can be expressed as:

$$\ln RHPR_t = \varsigma_0 + \pi_1 \ln OPR_t + \pi_2 \ln EPR_t + \pi_3 \ln NPR_t + \pi_4 \ln CPR_t + \pi_5 \ln GR_t + \mu_t, \quad (1)$$

where ς_0 is the constant, $\ln OPR_t$, $\ln EPR_t$, $\ln NPR_t$, $\ln CPR_t$ are the natural logarithm of energy prices. Following the importance of output growth in determining the house prices in a developed economy like the U.S., we included the natural logarithm of output growth ($\ln GR$) as control variable in the model. μ_t denotes zero mean white noise process with variance σ^2, $\varepsilon_t \sim iid(0, \sigma^2)$. The estimations of long- and short-run coefficients are performed through the ARDL, which is based on unrestricted error correction model (See Pesaran et al., 2001):

$$\begin{aligned} \Delta \ln RHPR = c_0 + \alpha_1 \ln HPR_{t-1} + \pi_2 \ln OPR_{t-1} + \pi_3 \ln EPR_{t-1} + \pi_4 \ln NPR_{t-1} \\ + \pi_5 \ln CPR_{t-1} + \pi_6 \ln GR_{t-1} + \sum_{i=0}^{p} \beta_{7,i} \Delta \ln RHPR_{t-i} + \sum_{i=0}^{q} \varphi_{8,i} \Delta \ln OPR_{t-i} \\ + \sum_{i=0}^{q} \varphi_{9,i} \Delta \ln EPR_{t-i} \end{aligned}$$

$$\sum_{i=0}^{p} \varphi_{10,i} \Delta \ln NPR_{t-i} + \sum_{i=0}^{q} \varphi_{11,i} \Delta \ln CPR_{t-i} + \sum_{i=0}^{q} \varphi_{12,i} \Delta \ln GR_{t-i} + \varepsilon_t, \quad (2)$$

where Δ is the first difference operator of the variables. The first part of Equation (2) estimates the long-run coefficients of energy prices and output growth, and the second part estimates the short-run coefficients of the variables. However, given the volatile nature of house price in the U.S. economy, there could be short-run disequilibrium in the system, whenever there is shock to the real house price. The speed at which the short-run disequilibrium adjusts to its long-run equilibrium path is determined by the error correction mechanism (ECM). Therefore, the ECM equation is based on the following:

$$\begin{aligned} \Delta \ln RHPR_t = \xi_0 + \sum_{i=0}^{p} \beta_i \Delta \ln RHPR_{t-i} + \sum_{i=0}^{q} \varphi_{1,i} \Delta \ln OPR_{t-i} \\ + \sum_{i=0}^{q} \varphi_{2,i} \Delta \ln EPR_{t-i} + \sum_{i=0}^{q} \varphi_{3,i} \Delta \ln NPR_{t-i} \end{aligned}$$

$$+ \sum_{i=0}^{q} \varphi_{4,i} \Delta \ln CPR_{t-i} + \sum_{i=0}^{q} \varphi_{5,i} \Delta \ln GR_{t-i} + \partial ECT_{t-1} + \varepsilon_t \quad (3)$$

where the adjustment speed to the long-run equilibrium level is captured by ECT_{t-1}. The short-run parameters are given by β_i, $\varphi_{1,i}$, $\varphi_{2,i}$, $\varphi_{3,i}$, $\varphi_{4,i}$, and $\varphi_{5,i}$. The choice of this method is based on its numerous advantages. Among these advantages are the obvious fact that it can be applied whether the variables are I(0), I(1) or integrated fractionally. More so, the performance of this test in a small sample size is better compared to other cointegration tests. To determine cointegration among variables, Pesaran et al. (2001) proposed an F-test. The null hypothesis for cointegration test is that $\pi_1 = \pi_2 = \pi_3 = \pi_4 = \pi_5 = 0$ and the alternative one is that $\pi_1 \neq \pi_2 \neq \pi_3 \neq \pi_4 \neq \pi_5 = 0$.

From Equation (2), we conduct a test to determine whether the pass-through of energy prices to real house price is complete or incomplete over the sample period. To achieve this objective, we apply a Wald test statistic with $H_0 : \pi_i = 1$ and $H_1 : \pi_i \neq 1$ in the long run while $H_0 : \varphi_i = 1$ and $H_1 : \varphi_i \neq 1$ in the short run.

3.4 | Causality analysis

The conditional Granger-causality proposed by Toda and Yamamoto (1995) is used to test for the causality between the variables in the model. This test of causality is perhaps known for its enviable advantageous properties compared to the existing causality tests. One of these advantages is that it accommodates whether the integrating properties of the series are I(0), I(1) or mutually cointegrated. The causality test by Toda-Yamamoto (1995) uses a modified Wald Statistic in testing for the directional causal relationship between the variables. The test is carried out based on the framework of Autoregressive

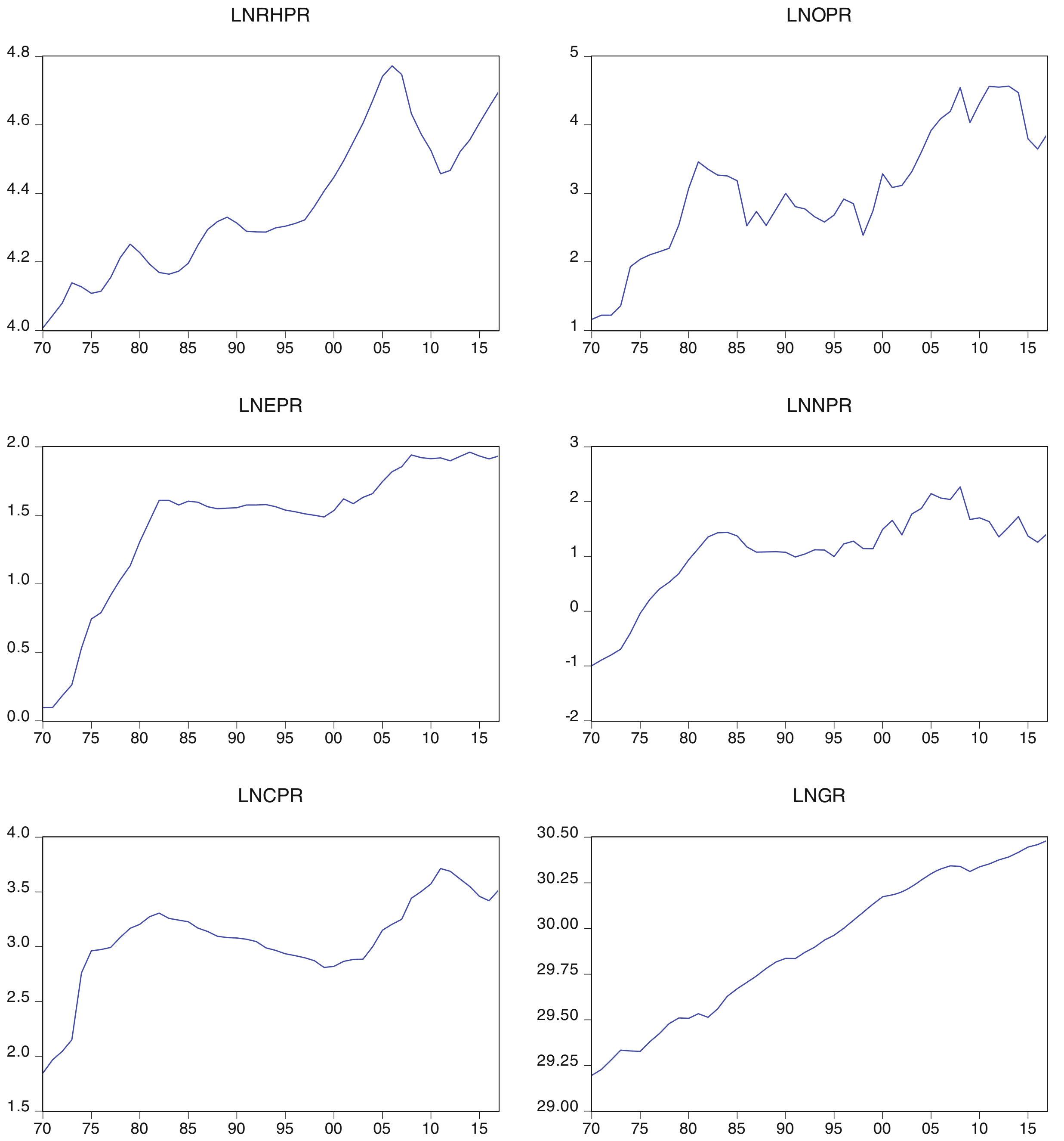

FIGURE 1 Time series plot of logs of RHPR, OPR, EPR, NPR, CPR, and GR

Distributed Lag (VAR) model. The null hypothesis states for example that oil price does not granger-cause real house price while the alternative hypothesis implies that oil price does Granger-cause real house price. This is applicable to all the variables in the model estimation.

4 | EMPIRICAL RESULTS AND DISCUSSION

We begin analysis by checking the visual properties of the time series we explored in this study. The aim is to check the possible drift, trend, seasonality, and structural breaks, which are commonly found in time series data (See Balcilar et al., 2019; Balcilar, Usman, & Musa, 2020; Balcilar, Roubaud, et al., 2020; Rafindadi and Usman 2019; 2020). The time series plots of the variables as reported in (Figure 1) suggest structural breaks in all the variables except output growth, which slopes upward indicating a time trend. The breaks identified in these variables may be attributed to the various economic and energy policies in the United States to accelerate and sustain the pace of economic growth, reduce greenhouse gas emissions, and improve the quality of environment.

The descriptive statistics and pairwise correlation results are presented in Table 1. The results show that all the variables are less volatile as the values of their standard deviations are ranging below one with oil price having the largest value. The reason for less volatile nature of oil price is that it is measured as the domestic first purchase price expressed in U.S. dollars per barrel, which is devoid of market arbitration. All the interested variables are negatively skewed with the exclusion of the real house price with all variables having positive kurtosis. Based on the Jarque-Bera test statistic, the distributions of the crude oil price, real house price, and output growth have a bell-shape in contrast to coal price, electricity price, and natural gas price. The pairwise correlation analysis reveals that crude oil price, coal price, electricity price, natural gas price, and output growth are positively correlated with real house price.

Testing the stationarity properties of the variables is an essential precondition to investigate the cointegration among the variables. For this reason, we applied the ADF and PP unit root tests. The results are presented in Table 2. According to these results, the variables of lnRHPR, lnEPR, lnNPR, and lnCOP are obviously stationary, while lnOPR and lnGR are stationary only in their first differences. Thus, we conclude that the variables under consideration are integrated of I (0) and I(1) i.e. mixed order of integration.

Since aforementioned variables are mixed order of integration, we proceed with the ARDL/bounds testing cointegration analysis to

TABLE 1 Descriptive statistics and pair-wise correlation matrix

Variable	LNRHPR	LNOILP	LNEP	LNNGP	LNCOPR	LNGR
Mean	4.363265	3.049684	1.443989	1.075702	3.064078	29.90557
Median	4.312336	3.034731	1.574846	1.201061	3.083743	29.91645
Maximum	4.771887	4.564244	1.960095	2.266958	3.713816	30.48202
Minimum	4.006949	1.156881	0.095310	−0.994252	1.846879	29.19540
Std. Dev.	0.207025	0.913948	0.506856	0.780473	0.406620	0.399471
Skewness	0.344667	−0.149392	−1.465198	−1.229609	−1.189034	−0.194648
Kurtosis	2.046816	2.526848	4.263538	4.055739	4.883055	1.682699
Jarque-Bera	2.767480	0.626289	20.36749	14.32467	18.40221	3.773664
Probability	0.250639	0.731144	0.000038	0.000775	0.000101	0.151551
Sum	209.4367	146.3848	69.31147	51.63370	147.0758	1435.467
Sum Sq. Dev.	2.014399	39.25916	12.07442	28.62949	7.770962	7.500115
Observations	48	48	48	48	48	48
LNRHPR	1.000000					
	–					
LNOPR	0.788870	1.000000				
	8.706013	–				
LNEPR	0.750525	0.889014	1.000000			
	7.702758	13.16845	–			
LNNPR	0.788183	0.877759	0.949156	1.000000		
	8.685992	12.42581	20.44905	–		
LNCPR	0.544830	0.860441	0.857099	0.767805	1.000000	
	4.406697	11.45285	11.28433	8.128044	–	
LNGR	0.930641	0.833200	0.842992	0.811229	0.619140	1.000000
	17.24883	10.21939	10.62869	9.409532	5.347404	–

Note: Source: Authors' computation.

TABLE 2 Unit root tests results

	ADF TEST		PP TEST	
	At level	First difference	At level	First difference
Ln RHPR				
Intercept	−0.9206	−3.8380***	−1.1002	−2.7489*
Intercept & Trend	−4.3620***	−3.8039**	−2.4108	−2.6998
Ln OPR				
Intercept	−1.9450	−6.0309***	−1.9450	−6.0355***
Intercept & Trend	−2.0548	−6.0856***	−2.1649	−6.0886***
Ln EPR				
Intercept	−4.0974***	−3.2864**	−3.6895***	−3.3371**
Intercept & Trend	−3.5670**	−4.0423**	−2.3164	−4.1852***
Ln NPR				
Intercept	−3.1452**	−6.1019***	−3.1434**	−6.2344***
Intercept & trend	−1.9056	−6.7925***	−1.9072	−6.8106***
Ln COP				
Intercept	−3.4549**	−4.9920***	−1.2177	−4.1828***
Intercept & trend	−1.9532	−5.1211***	−2.0570	−4.1107**
Ln GR				
Intercept	−1.8782	−4.9091***	−1.9660	−4.7077***
Intercept & Trend	−1.5100	−5.1189***	−1.0733	−4.9075***

Note: ***, **, and * denote 1%, 5%, and 10% significance levels at which the null hypothesis of non-stationarity is rejected for all tests except the KPSS test. In the case of KPSS, *** and ** denote significance levels of 1% and 5% at which the null hypothesis of stationarity is not rejected.

TABLE 3 Results of the ARDL bounds testing cointegration

	Statistic	K
F-Statistic	3.6647***	5
Critical value bound	Lower I (0)	Upper I (1)
10%	2.26	3.35
t-Statistic	−4.0059	5
Critical value bound	Lower I (0)	Upper I (1)
10%	−2.57	−3.86

Note: *** denotes significance level at 10% accordingly.

establish a long-run interaction among investigated variables. Therefore, Table 3 discloses the findings based on the ARDL bounds testing cointegration. According to the results, the values of estimated F-statistic and *t*-statistic are greater than the upper bounds critical values for the tests at 10% level of significance. Thus, we conclude that a stable long-run equilibrium nexus among the variables captured in the model.

To estimate the long-run and short-run parameters of the relationship between all the disaggregated energy prices and real house price in the US, we apply the ARDL model which is suitable for where the variables are integrated of both order zero I(0), I(1) or mutually cointegrated. The results of the model estimations are presented in Table 4. The long-run analysis reveals that crude oil price and electricity price negatively affect real house price. This indicates that under the ceteris paribus condition, a 1% increase in crude oil and electricity price decrease real house price by almost 0.03% and 0.34%, respectively. However, only the effect of electricity price is statistically significance at 5% level. Furthermore, house price is positively affected by a percentage change in all other explanatory variables including the controlled variable captured. Specifically, a 1% change in natural gas price, coal price, and output growth increases real house price by 0.19%, 0.25%, and 0.54%. These results are statistically significant.

Furthermore, like the long-run parameters, the short-run findings show that crude oil price and electricity price have a negative relationship with real house price. However, only the effect of electricity price is statistically significant at 5% level. Specifically, the results indicate that a 1% increase in oil price and electricity price leads to almost 0.03% and 0.14% decreases in real house price respectively. On the contrary, it is found that natural gas price, coal price, and output growth have a positive effect on real house price. The results therefore means that a 1% increase in natural gas price, coal price, and output growth causes almost 0.08%, 0.11%, and 0.22% increase in real house price while holding other factors constant. The coefficient of error correction term (Ec_{t-1}) is negative and statistically significant, which verifies the established cointegration relationship among the variables. The coefficient of the error correction, which indicates the speed of adjustment, implies that the short run deviations from the long run equilibrium are corrected by 42.73% in each year via the channels of oil price, coal price, electricity price, natural gas price, and output growth in the United States. Finally, the diagnostic tests results

TABLE 4 Long-run and short-run ARDL coefficients

Dependent variable = lnRHPR			
Variable	**Coefficient**	**T-statistic**	***p*-value**
lnOPR	−0.0706	−1.5444	0.1341
lnEPR	−0.3356**	−2.4786	0.0197
lnNPR	0.1925***	3.3191	0.0026
lnCPR	0.2500**	2.6743	0.0126
lnGR	0.5374***	8.5992	0.0000
ec_{t-1}	−0.4173***	−5.1049	0.0000
ΔlnOPR	−0.0295	−1.5423	0.1346
ΔlnEPR	−0.1400**	−2.2850	0.0304
ΔlnNPR	0.0803**	2.5962	0.0151
ΔlnCPR	0.1043**	2.3357	0.0272
ΔlnGR	0.2243***	4.3417	0.0002
Constant	−4.9854***	−4.1499	0.0003
Diagnostic test	**Statistic**		**Prob. value**
χ^2SERIAL	2.7881: [1]		0.1070
χ^2ARCH	0.9928: [1]		0.3249
χ^2RESET	0.0953: [1]		0.7600
χ^2NORMAL	0.9433		0.6239

Note: Optimal lag length for the model is 4 via AIC and unrestricted constant and no trend. ***, **, and * denote significance levels at 1%, 5%, and 10%. χ^2_{SERIAL}, χ^2_{ARCH}, and χ^2_{RESET} denote the Breusch–Godfrey LM test for serial correlation, conditional heteroscedasticity ARCH, Ramsey RESET test for functional form of the model. [] represents the optimal lag selection for diagnostic tests.

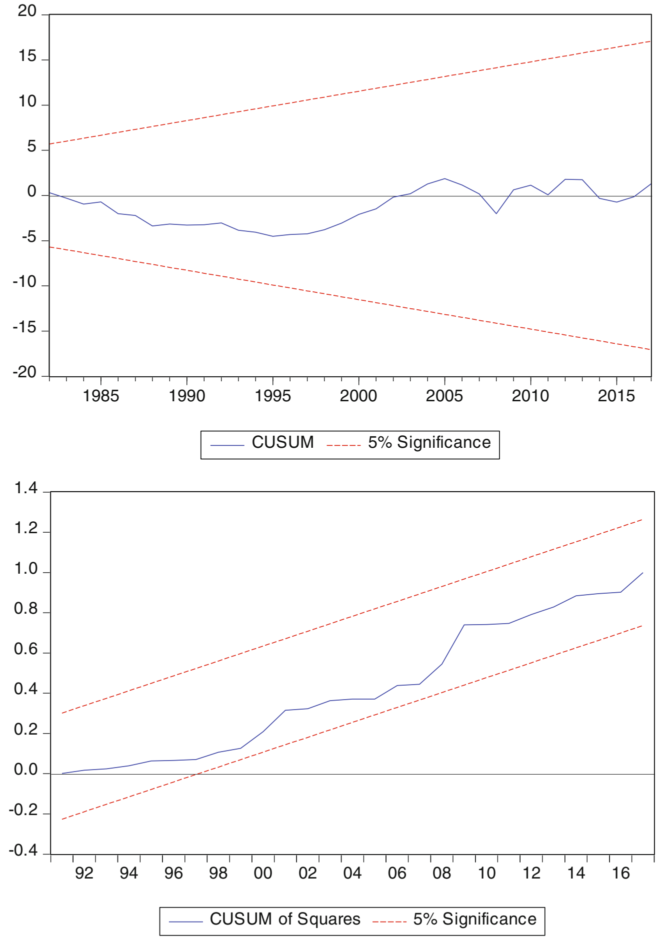

FIGURE 2 CUSUM and CUSUM squared

confirm that error term of the model does not have serial correlation and heteroscedasticity problems. The Ramsey RESET test also provides that the functional form of the model is well specified. To test for the stability of the model, the current study employs cumulative sum of recursive residuals (CUSUM) and CUSUM squared (CUSUMsq) as proposed by Brown et al. (1975). Figure 2 provides clearly that the ARDL model estimations easily pass the test of stability at 5% critical bounds, indicating that the ARDL model employed is stable in the long run and short run.

We perform a test to determine whether the pass-through of disaggregated energy prices to real house price is complete or incomplete by using a WALD test statistic. The results as documented in Table 5 show that the coefficient of F-test is statistically significance at 1% level in all the energy prices except for the crude oil price, which is insignificant even at 10% level. This result suggests that the null hypothesis of complete pass-through cannot be rejected for all the coefficients in both long run and short run except for crude oil price in the long run. Therefore, our finding implies that the pass-through of energy prices to real house price is partial and incomplete while the long run pass-through of oil price to real house price is full and complete even though the coefficient is not statistically significant. The incomplete pass-through of energy prices is aligned with the recent literature that the pass-through elasticities have been dampening along the price chain due to low and stable inflation rate as found in McCarthy (2000), Campa et al. (2004), Gagnon and Ihrig (2004), Devereux and Yetman (2010), Lariau et al. (2016), Usman & Elsalih, (2018); Balcilar et al. (2019); Balcilar, Roubaud, et al. (2020), Usman (2020). Moreover, the finding of incomplete pass-through concurs with Ganapati et al. (2016) who found that the marginal costs pass-through is incomplete.

The presence of cointegration among variables signifies the existence of causality between the variables. Therefore, to examine the direction of causality, we apply conditional Granger causality test based on the Block Exogeneity Wald Tests. The results are reported in Table 6. Particularly, the results provide the existence of bidirectional Granger-causality between real house price and natural gas price and again between real house price and output growth. The result also suggests the feedback causal relationship between natural gas price and real house price, output growth and real house price, natural gas price and crude oil price, coal price and electricity price as well as output growth and coal price. On the basis of unidirectional causality, the results found a causal relationship running from coal price, real house price, crude oil price, and natural gas price to electricity price in the United States. We also found that crude oil price is the cause of coal price in Granger causality sense. The implication of the directional causal relationship found suggests that the causal variable

TABLE 5 Test of pass-through

Null hypothesis	F-statistic	p-value	Decision
Long-run pass-through			
$C(\pi_2) = 1$	1.3592	0.2539	Complete pass-through
$C(\pi_3) = 1$	36.440	0.0000	Incomplete pass-through
$C(\pi_4) = 1$	79.416	0.0000	Incomplete pass-through
$C(\pi_5) = 1$	2904.8	0.0000	Incomplete pass-through
Short-run pass-through			
$C(\varphi_8) = 1$	2053.7	0.0000	Incomplete pass-through
$C(\varphi_9) = 1$	225.95	0.0000	Incomplete pass-through
$C(\varphi_{10}) = 1$	187.53	0.0000	Incomplete pass-through
$C(\varphi_{11}) = 1$	442.92	0.0000	Incomplete pass-through

Note: Source: Authors computation.

TABLE 6 Causality test

Dependent variable	$\ln RHPR_t$	$\ln OPR_t$	$\ln EPR_t$	$\ln NPR_t$	$\ln CPR_t$	$\ln GR_t$	All $\chi^2 - stat$
$\ln RHPR_t$	–	4.9442 (0.2931)	3.1008 (0.5411)	11.837** (0.0186)	5.3018 (0.2577)	10.668** (0.0306)	43.103*** (0.0020)
$\ln OPR_t$	3.2790 (0.5123)	–	5.6900 (0.2235)	9.2906* (0.0542)	1.9775 (0.7399)	1.4829 (0.8297)	30.257* (0.0658)
$\ln EPR_t$	10.513** (0.0326)	33.228*** (0.0000)	–	11.821** (0.0187)	17.344*** (0.0017)	1.2273 (0.8736)	99.975*** (0.0000)
$\ln NPR_t$	18.014*** (0.0012)	22.651*** (0.0001)	6.6551 (0.1553)	–	2.7706 (0.5969)	0.2492 (0.9929)	44.309*** (0.0014)
$\ln CPR_t$	19.532*** (0.0006)	18.966*** (0.0008)	8.0221* (0.0908)	5.0583 (0.2814)	–	14.123** (0.0069)	139.08*** (0.0000)
$\ln GR_t$	11.597** (0.0206)	5.5137 (0.2385)	3.0015 (0.5576)	7.0193 (0.1349)	12.566** (0.0136)	–	51.816*** (0.0001)

Note: ***, **, and * denote significance level at 1%, 5%, and 10%, respectively. The lag length is 4. *p*-values are given in brackets ().

has additional information about the future value of predicted variable. Such information is required for a sound environmental and energy policymaking. Therefore, the results echo the finding of Atil et al. (2014) who found an asymmetric pass-through of crude oil prices to gasoline and natural gas prices. Similarly, the finding of this study concurs with Lahiani et al. (2017) who revealed that the pass-through of oil prices to a set of energy prices is statistically significant.

5 | CONCLUSIONS AND POLICY IMPLICATIONS

This study aimed to critically investigate the dynamic pass-through of energy prices (oil, electricity, natural gas, and coal prices) to real house price in the United States over the period of 1970–2017. The study employed the ADF and PP non-stationarity tests to examine the stochastic properties of the investigated series. In all, the results showed that all the series are stationary at levels and first differences. To this end, we applied the bounds test cointegration method. We found the presence of a stable long-run equilibrium relationship among the investigated variables. We therefore applied ARDL estimation procedure to obtain the long-run and short-run coefficients. The results disclosed that the long-run and short-run relationships between crude oil price and real house price as well as electricity price and real house price were negative and inelastic. However, the coefficient of electricity price was only statistically significant while crude oil price was not both in the long-run and short-run dynamics. Also, the long-run and short-run effects of natural gas price, coal price and on real house price were positive, elastic and significant. As already stated, output growth was included in the model estimation as a control variable. The result provided that the effect of output growth on real house price was positive, inelastic, and highly statistically significant at 1% level of significance both in the long run and short run, respectively.

To test whether the pass-through was complete or incomplete, we applied the Wald test statistic on all the energy prices both in the long run and short run. The result of these tests showed unequivocally that the null hypothesis of complete pass-through was rejected in all the energy prices except for long-run effect of crude oil price, which could not be rejected. This means that the pass-through of energy prices to real house price in the United States is incomplete both in the long run and short run except for crude oil price which was complete in the long run. Furthermore, the results of the causality indicated that a feedback effect was found between real house price and natural gas price, real house price and output growth, crude oil price and natural gas price, electricity price and coal price, and coal price and output growth. In addition, a unidirectional causal relationship is running from crude oil price, real house price, and natural gas price to electricity price. More so, crude oil price in the Granger sense was the cause of coal price in the United States.

Therefore, based on these findings, it is worth noting that the disaggregated energy prices are poised to provide better information for policy framework especially for an energy-driven economy like the United States. However, the design of energy-targeted policies in the United States should incorporate inter-sectoral (at least the high-risk sector) information to achieve effective implementation. In doing so, it will (at least) expectedly reduce the spillover effects from other sectors unlike the downturn in the U.S. Subprime Mortgage sector during the GFC. Although the U.S. energy import gap has declined to about 1.5 times more than its exports between 2007 and 2017, the total value of energy imports has remained high (US EIA, 2018). Also, considering that crude oil import in the U.S. accounts for about two-thirds of total primary energy import, the country recently became net exporter of natural gas in 2017 (US EIA, 2018). Then, the empirical evidence of incomplete long-run pass-through of energy prices and output growth to real house price is awakening that energy policy in the country should be tailored toward all the disaggregated energy prices. Hence, the focus of the government, energy experts, and energy stakeholders should be toward further diversification of the country's energy sector to accommodate effective development of energy portfolios. Moreover, the incomplete pass-through of energy prices suggests that real house prices are relatively sticky in the United States. Therefore, energy prices (with exception of oil price) could be a hedging instrument for the U.S. real house price. However, the effective implementation of the aforementioned policies could be dependent on conducting a contextual state-level study. Hence, further studies are recommended to focus on all the states of the country rather than national study as contained in the current study. Lastly, further study could examine potential asymmetric relationship or the association among the examined indicators in varying or regime switching models.

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CONFLICTS OF INTEREST

The authors wish to disclose here that there are no potential conflicts of interest at any level of this study.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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