An empirical examination of the relationship between the US-Canada exchange rate and commodity prices

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Econ809: Project 2

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PART 1: US-CANADA EXCHANGE RATE AND TOTAL COMMODITY PRICE INDEX

1. Introduction

The present value approach to exchange rate determination predicts that current values of nominal exchange rate are determined by the expected future values of its fundamentals (Chen et al, 2010). This implies that the current nominal exchange rate contains information to forecast future values of its fundamentals. Applying this to the relationship between exchange rates and commodity prices, the present value approach hypotheses that exchange rates should Granger-Cause commodity prices. Studies such as Chen et al. (2010) provided empirical evidence that supports this theory. In this project, I examine the relationship between the US-Canada exchange rate and total commodity prices. Using monthly time series from December 1972 to April 2017, I investigate whether the US-Canada exchange rate Granger-Causes total commodity prices as the present value approach predicts. The study is structured as follows; section 2 discusses the present value approach and how it relates to exchange rates and commodity prices; section 3 discusses the methodology employed; section 4 presents the results; and section 5 concludes.

2. Theoretical Framework

This section presents a discussion of the theoretical underpinnings of the study. The extant literature has employed several theories to explain the relationship between exchange rates and commodity prices. Among them are the portfolio balance approach, the Sticky price model, and the present value approach. Following the work of Chen et al. (2010), this study is grounded on the present value approach as the theoretical foundation to examine the relationship between exchange rates and commodity prices. Thus, the empirical analysis of this study is informed and directed by this theory.

The Present Value Approach

The present value (PV) approach is an asset pricing approach to exchange rate determination (Chen et al., 2010). The theory establishes a relationship between nominal exchange rate and the fundamentals of an economy. These fundamentals may include interest rates, inflation, and money supply, among others. The fundamental of interest to this study is commodity prices. According to the PV, the nominal exchange rate is determined by the future values of its fundamentals. More specifically, considering the relationship between exchange rates and commodity prices, the theory posits that the current nominal exchange is the discounted sum of expected future commodity prices. This relationship is modeled by the following present value equation as presented by Chen et al. (2010):

$$s_t = \gamma \sum_{j=0}^{\infty} \psi^j E_t(f_{t+j}|I_t),$$

where s_t is the nominal exchange rate, f_{t+j} is the future values of fundamental (i.e., future commodity prices), E_t is the expectation operator, I_t represents information, γ, and ψ are parameters of the model. The equation above implies that nominal exchange rate is a function of expected future commodity prices given information. That is, movement in the nominal exchange rate precedes movements in commodity prices. Hence, according to the present value approach, the exchange rate should Granger-Cause commodity prices.

According to Chen et al. (2010), the present value approach presents two key identification issues: 1) simultaneity bias – exchange rate and its fundamentals may be endogenously determined, and

2) reverse causality – a bi-directional relationship between the variables. In the presence of these issues, a finding that exchange rate Granger-Causes its fundamentals could simply be the result of endogenous response or reverse causality and not evidence of present value framework. However, Chen et al. (2010) further advance that, unlike other fundamentals such as money supply, interest rate, and inflation which are endogenously determined with exchange rates, commodity prices are unique. Unique because there are exogenous to "commodity-currency" countries such as Canada. Hence, issues of endogeneity and reverse causality that may interfere with the relationship between exchange rate and commodity prices are ruled out. As a result, we proceed to test the hypothesis that exchange rate Granger-Causes commodity prices.

3. Methodology and Data

This section discusses the data used in this study and the empirical tools needed to achieve the objective of the study.

3.1 Empirical Approach

The objective of this study is to investigate the relationship between the US-Canada exchange rates and commodity prices. The present value approach hypotheses that exchange rate should Granger-Cause commodity prices. Several time series analysis procedures are employed in the proceeding sections to establish the validity of this hypothesis. First, I examine the stationarity of the exchange rate and commodity price variables using the Augmented Dickey-Fuller (ADF) unit root test. Second, I perform a cointegration test to examine the long-run relationship between exchange rates and commodity prices. Depending on the results from the cointegration test, I either estimate the

Vector Autoregressive Model (VAR) or the Vector Error Correction Model (VECM). Then I test the Granger-Causality between exchange rate and commodity prices. Finally, I perform stability tests and residual diagnostics tests to check the robustness and validity of the results.

3.2 Data Description

The study uses secondary data on the monthly US-Canada exchange rate and total commodity price index. This data covers the period from December 1972 to April 2017. It was obtained from Statistics Canada; the commodity price indices are in Table 10-10-0132-01 and exchange rates were in Table 10-10-0009-01. The total commodity price index is deflated by the US-CPI which was obtained from the U.S Bureau of Labor Statistics.

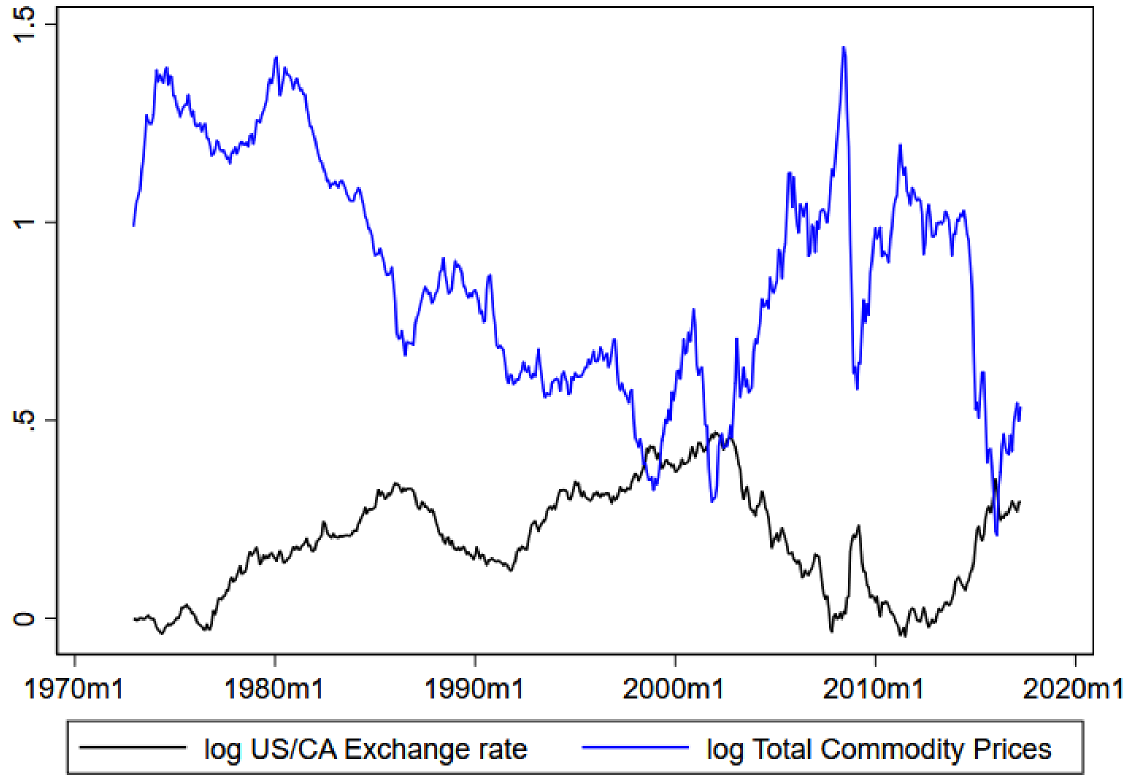
Table 1: Description of Variables

Variable	Description	Source
Exchange Rate	United States Dollar in terms of Canadian Dollar, Monthly	Statistics Canada, Table 10-10-0009-01
Total Commodity Price Index	Fisher Commodity Price Index for all commodities, in terms of US Dollar, Monthly	Statistics Canada, Table 10-10-0132-01
US CPI	U.S Consumer Price Index, Average Price Data	U.S Bureau of Labor Statistics

4. Empirical Analysis

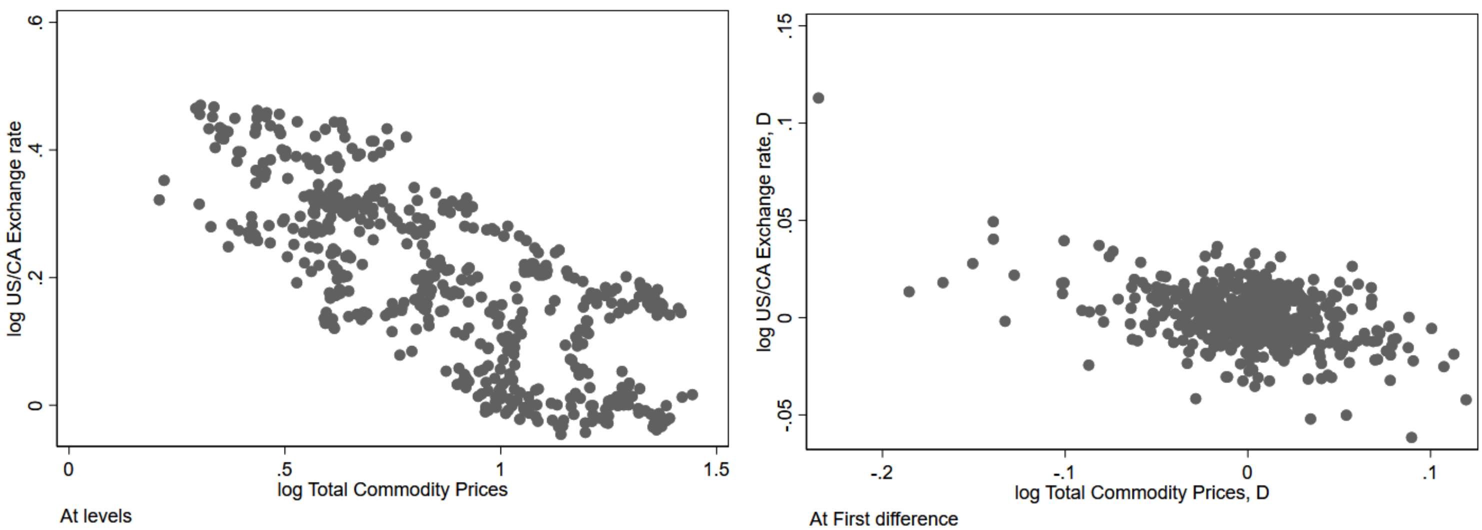
4.1 Descriptive Statistics

*Figure 1: US-Canada Exchange rate (log) and Total Commodity Price Index (Deflated, log) from 1972m12 to 2017m4***.**



Over the period from 1972 to 2017, there has been a marked divergence between the US-Canada exchange rate and the total commodity price index. In figure 1 above, observe that while exchange rate trended upwards from 19702 to the early 2000s, the total commodity price index trended downwards over the same period. Between the early 2000s to around 2008, commodity prices rose steeply to a peak in 2008 (during the financial crises) while the US-Canada exchange trended downwards. The same divergence can be observed from 2011 onwards. This suggests an inverse relationship between the US-Canada exchange rate and commodity prices thus an appreciation of the Canadian dollar is associated with increased commodity prices. In figure 2, the exchange rate has a strong negative correlation with commodity prices. However, this correlation weakens significantly after taking the first differences of the variables implying that the observed correlation may be spurious. Hence, there is a need for further investigation of the relationship between the two variables.

Figure 2: Association between the US-Canada Exchange rate and Total Commodity prices at levels and first difference



4.2 Unit Root Test

A unit root test is used to determine whether a time series variable is non-stationary and possesses a unit root. A series is said to be (weakly) stationary if it has a constant mean, finite variance, and constant autocovariance which is the only function of the distance between the observations. The exchange rate and total commodity price index may be erroneously correlated when they are non-stationary and statistically independent. Therefore, to prevent spurious regression, I employ the Augmented-Dickey Fuller (ADF) test to ascertain the stationarity statuses of the variables. The null hypothesis is generally defined as the presence of a unit root and the alternative hypothesis is stationarity.

Table 2: Summary of Augmented Dickey-Fuller Unit Root Tests

Variable	Unit Root Status	Optimal Lags (AIC)
US-Canada Exchange rate (log)	I (1)	2
Total Commodity Prices (Deflated, log)	I (1)	3

Table 2 provides a summary of the ADF unit root tests. Exchange rate and total commodity price index are integrated of order 1 (i.e., I (1)) with optimal lag orders of 2 and 3 respectively. That is, both variables are non-stationary at levels and have a unit root. This implies that the observed correlation between them maybe indeed spurious. In the next section, I perform a cointegration test to determine whether these variables have a long-run relationship.

4.3 Cointegration Tests

A cointegration test is used to establish whether there is a long-run relationship between two or more time series (Marinucci & Robinson, 2001). Two or more I (1) variables are said to be cointegrated if a linear combination of them is I (0). I test for the long-run relationship between the US-Canada exchange rate and the total commodity price index using both the single-equation approach and the Johansen test. Note that from the unit root tests, both variables are I (1).

From the regression, exchange rate has a negative and significant on total commodity prices (see Appendix A5). I estimate the residuals from the regression and perform an ADF test to determine whether there is a unit root. The result of the ADF test on the residual is presented in table 3 below. I fail to reject the null hypothesis of unit root at a 5% significance level. Thus, the residual is I (1). The Johansen tests for cointegration with 3 lags also show that there are zero cointegrating equations (Appendix A5). This implies that there is no evidence of a long-run relationship between the US-Canada exchange rate and the total commodity price index. Since there is no long-run relationship, the following section estimates the Vector Autoregressive Model to investigate whether there is a short-run relationship between the variables.

4.4 Vector Autoregressive Model (VAR)

VAR is used to estimate the short-run relationship between time series variables. VAR is appropriate when the variables are not integrated i.e., there exists no long-run relationship between them. In our case, we found that the US-Canada exchange rate and total commodity price index are both I (1) and not cointegrated. Therefore, we estimate the VAR model using the first difference of the variables with 2 lags as shown in Table 3. In model (1), we observe that only the first lag of total commodity prices has a significant effect on its current prices. The exchange rate has no significant short-run effect on the total commodity price index. Model (2) also shows that only the previous year's value of the exchange rate significantly affects its current value. This result implies that there is exist no short-run relationship between the US-Canada exchange rate and the commodity price index.

Table 3: Estimation Results of the VAR Model

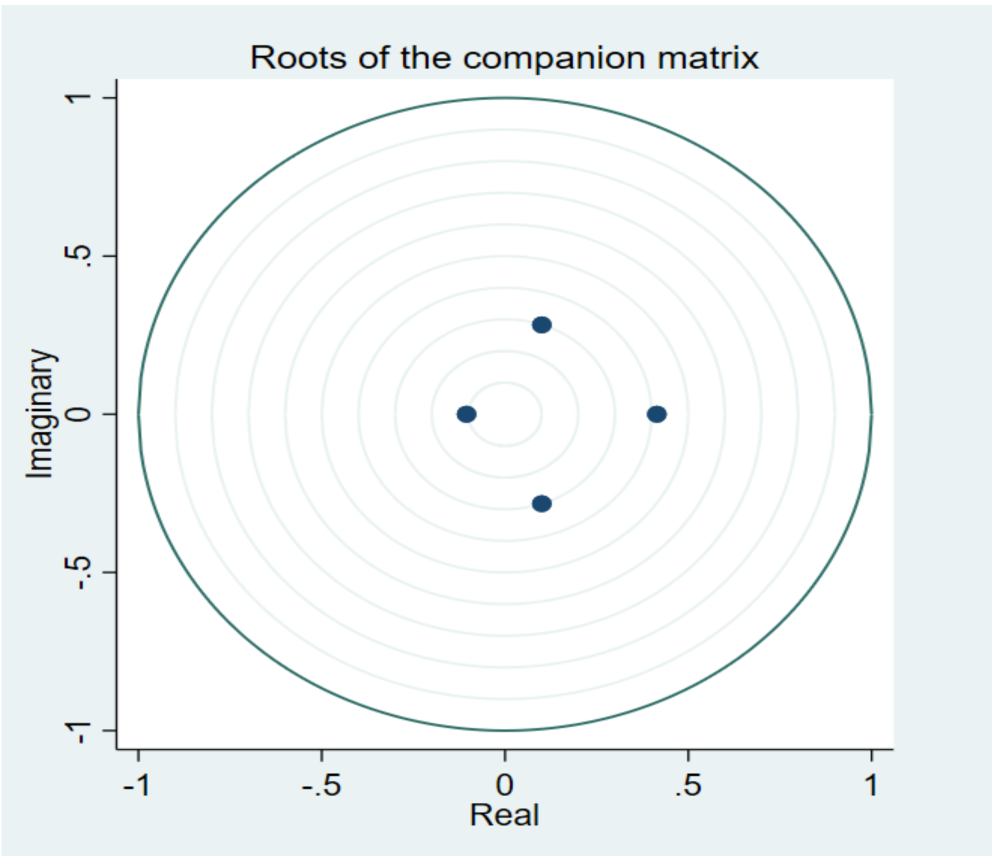
	Dependent Variables	
Independent Variables	(1) D_lnprice_real	(2) D_lnexr
LD_lnprice_real	.251***	-.0318
L2D_lnprice_real	.021	-.0136
LD_lnexr	-.117	.258***
L2D_lnexr	-.183	-.068
time	-2.81e-06	-1.98e-06
_cons	.000	.001

Note: * indicates p-value < 0.01**

4.5 Stability Analysis

The stability of the VAR system simply implies stationarity. If all inverse roots of the characteristic AR polynomial have a modulus less than one and lie inside the unit circle, the estimated VAR is stable. However, if the VAR is not stable, diverse tests conducted on our VAR model may be invalid. Figure 3 presents the results of the stability test of our VAR model. There are four roots, and they all lie within the unit circle. Therefore, the VAR is stable.

Figure 3: Stability Test of the VAR Model



4.6 Diagnostic Tests

I perform diagnostic tests on the residuals of the VAR model. Specifically, I check for autocorrelation and normality of the residuals. The results of the Lagrange-Multiplier test for autocorrelation and the normality tests are included in Appendix A7. The LM shows that there is no autocorrelation. Jarque-Bera, Skewness, and Kurtosis tests show that the residual of the VAR model is not normally distributed.

4.7 Granger-Causality Test

The Granger-Causality (GC) test examines if lagged values of one variable help to predict other variables in the model. I perform the GC tests to investigate whether past (lagged) values of exchange rate can predict the total commodity price index as predicted by the present value model.

Granger test:

- Ho: US-Canada Exchange rate does not Granger Cause Total Commodity Price Index
- H1: US-Canada Exchange rate Granger Cause Total Commodity Price Index

Decision rule

- If the p-value is less than 0.05: US-Canada Exchange rate Granger Causes Total Commodity Price Index at the 5% significance level.
- Else, the US-Canada Exchange rate does not Granger cause Total Commodity Price Index at the 5% significance level.

Table 4: Granger Causality Test

Source	SS	df	MS
Model	.07504758	5	.015009516
Residual	.735462212	524	.001403554
Total	.810509792	529	.001532155

Number of obs	=	530
F(5, 524)	=	10.69
Prob > F	=	0.0000
R-squared	=	0.0926
Adj R-squared	=	0.0839
Root MSE	=	.03746

dlnprice_real	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
time	-2.81e-06	.0000107	-0.26	0.792	-.0000237	.0000181
dlnexr						
L1.	-.1174411	.1275624	-0.92	0.358	-.3680376	.1331554
L2.	-.1826277	.1274974	-1.43	0.153	-.4330965	.0678411
dlnprice_real						
L1.	.2507374	.0479048	5.23	0.000	.1566283	.3448464
L2.	.0209526	.0479325	0.44	0.662	-.073211	.1151161
_cons	.0006359	.0047878	0.13	0.894	-.0087697	.0100415

```
. test (L.dlnexr) (L2.dlnexr)

 ( 1)  L.dlnexr = 0
 ( 2)  L2.dlnexr = 0

       F(  2,   524) =    1.82
            Prob > F =    0.1626
```

The result of the Granger-Causality test is presented in table 4 above. The results show that the first and second lags of exchange rate have no significant (at 5% level) effect on the total commodity price index. We fail to reject the null; thus, the US-Canada exchange rate does not Granger-Cause total commodity price index.

5.0 Conclusion

According to the present value approach to exchange rate determination, current nominal exchange rates Granger-Causes commodity price index. A large strand of such studies has confirmed that exchange rates and commodity prices have both short-run and long-run relationships (for example Liu et al., 2020; Chen et al., 2010). Furthermore, as the present value approach predicts, these studies established that exchange rates can predict commodity prices. In this study, I investigated the relationship between the US-Canada exchange rate and the commodity prices of Canada using monthly time series data from December 1972 to April 2017.

US-Canada exchange rate and total commodity prices were found to be inversely associated when studied at levels and first differences. However, further analysis suggests that the observed association is spurious because the variables have unit roots and are not cointegrated. This implies that there exists no evidence of a long-run relationship between the variables. The results from the VAR model also suggest the absence of a significant short-run relationship between the variables. Furthermore, contrary to the findings of other studies such as Chen et al. (2010), this study reveals that the US-Canada exchange rate does not Granger-Cause total commodity price index. Thus, the present value approach is not supported by the empirical evidence in this paper.

PART 2 – RELATIONSHIPS BETWEEN COMMODITY PRICE INDICES

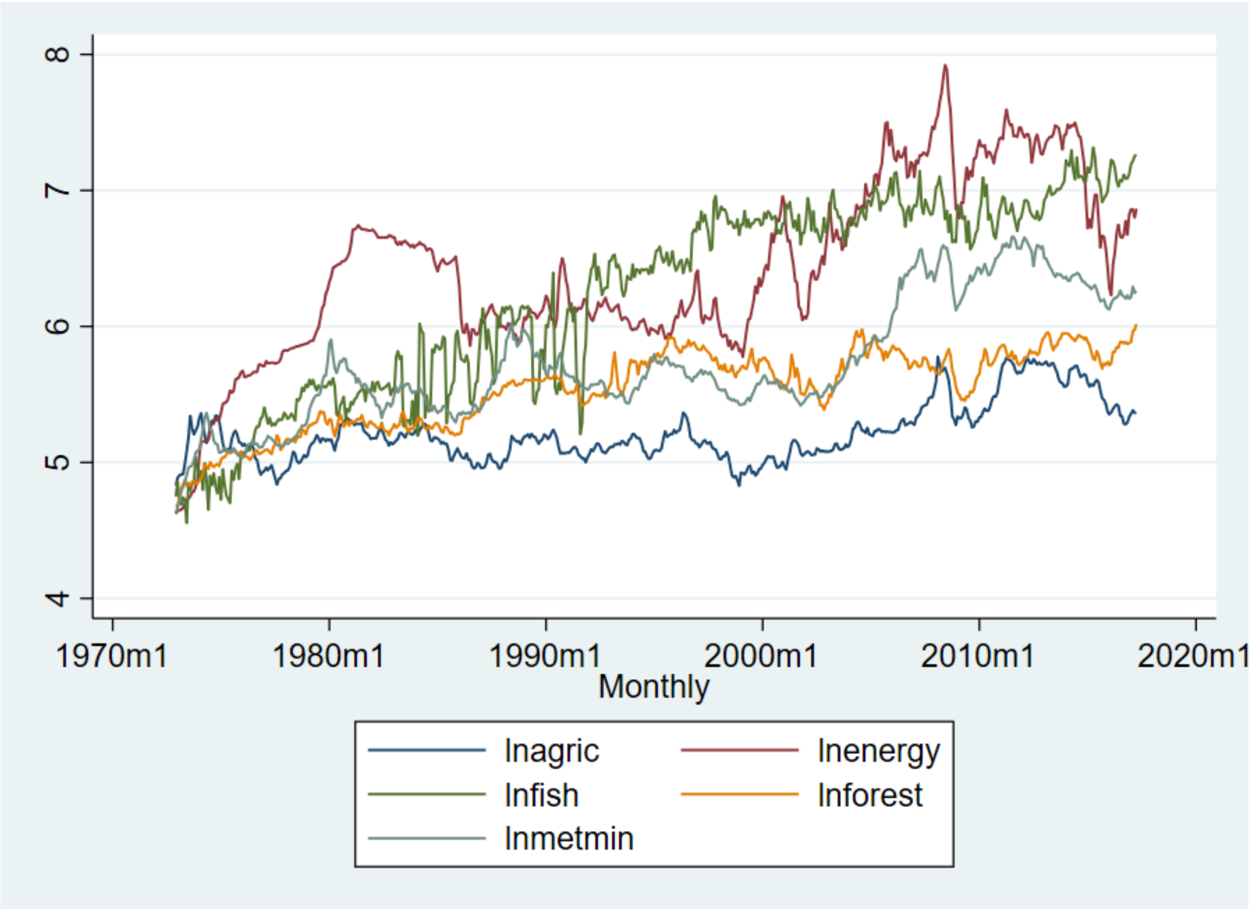
1. Introduction

In this part of the project, I examine the relationship between the five commodity price indices: Agriculture, Energy, Fish, Forest, and Metals and Minerals. The main objective of this part is to investigate whether these commodity prices share the same permanent shocks. That is, do some of these prices move together in the long run? Are they cointegrated? The following sections provide empirical evidence to answer this question.

2. Descriptives Statistics

Overall, commodity price indices have increased steadily over the period from 1972 to 2017. Figure 4 shows that although all five commodity prices are trending upward over the long term, this growth is not uniformly distributed among the various types of commodities. For instance, compared to the other commodity prices, prices of energy and fish have a steeper trend which indicates that these prices have risen faster than the others. Furthermore, Energy and Fish prices also have higher prices compared to the other commodities and they both have a high fluctuation as well. From the figure, we can also notice that the Agriculture price index has been consistently lower than all other commodity prices over the period. Also, the flatter trend of the Agriculture and Forest price indices indicates that the prices have not grown much over time.

Figure 4: Commodity Prices Indices from 1972 - 2017



Tables 1 and 2 show the correlation between the commodity price indices at levels and the first difference. We can observe that all the variables have a strong positive and highly significant correlation at levels. At first difference, the strength of the correlation reduces considerably, and some correlations become insignificant. For example, there is no significant correlation between Fish and Energy, Forest and Energy, Forest and Fish, and Fish and Metals and Minerals. Notice that all prices are still significantly correlated with Agriculture prices. The observed correlation provides a reason to investigate the variables further.

Table 1: Pairwise correlations at levels

Variables	(1)	(2)	(3)	(4)	(5)
(1) lnagric	1.000				
(2) lnenergy	0.690*	1.000			
(3) lnfish	0.433*	0.686*	1.000		
(4) lnforest	0.447*	0.642*	0.903*	1.000	
(5) lnmetmin	0.799*	0.849*	0.734*	0.744*	1.000

**** p<0.01, ** p<0.05, * p<0.1*

Table 2: Pairwise correlations at first difference

Variables	(1)	(2)	(3)	(4)	(5)
(1) D.lnagric	1.000				
(2) D.lnenergy	0.132*	1.000			
(3) D.lnfish	0.089*	0.010	1.000		
(4) D.lnforest	0.124*	0.051	0.023	1.000	
(5) D.lnmetmin	0.164*	0.237*	0.076	0.142*	1.000

**** p<0.01, ** p<0.05, * p<0.1*

3. Unit Root

The results of the unit root test are summarized in table 3 below. All the variables are non-stationary at levels. They are all cointegrated of order 1 i.e., I (1). The optimal lag orders presented in the table are selected based on the Akaike Information Criteria (AIC). Since all the variables are I (1), I proceed to test whether there exists a long-run relationship between them using the Johansen cointegration test.

Table 3: Summary of ADF Unit Root Tests Commodity Price Indices (log)

Variable	Unit Root Status	Optimal Lags
Agriculture	I (1)	4
Energy	I (1)	2

Fish	I (1)	4
Forest	I (1)	3
Metals and Mineral Price Index (log)	I (1)	2

4. Cointegration

Table 4: Johansen Cointegration Test for the Commodity Price Indices

```
. vecrank lnenergy lnmetmin lnagric lnfish lnforest, lags(2) trend(trend)

Johansen tests for cointegration
Trend: Linear                                 Number of obs  = 531
Sample: 1973m2 thru 2017m4                    Number of lags =   2
______________________________________________________________________________
                                                              Critical
Maximum                                              Trace      value
   rank  Params          LL   Eigenvalue   statistic         5%
      0      35   4196.6995            .    138.0883      77.74
      1      44   4231.9721      0.12441     67.5430      54.64
      2      51   4249.0783      0.06240     33.3307*     34.55
      3      56   4257.8988      0.03268     15.6895      18.17
      4      59   4263.3868      0.02046      4.7135       3.74
      5      60   4265.7436      0.00884
______________________________________________________________________________
* selected rank
```

I perform the Johansen test for the cointegration of the five commodity price indices with 2 lags and a trend. The optimal lag order was selected based on the AIC. From table 4, at maximum rank 2, the trace statistic (33.33) is less than the 5% critical value (34.55). Hence, we fail to reject the null hypothesis of 2 cointegrating equations. Thus, there exist two cointegrating equations which imply that the variables are cointegrated. That is, there exists a long-run relationship between the variables. This finding provides evidence that some of the commodity prices share the same permanent shocks.

Out of curiosity, I extend the analysis to investigate short-run and long-run relationships using the Vector Error Correction Model. It is possible to estimate VECM since all the variables are I (1) and also cointegrated. The detailed results of the VECM, stability test, and diagnostic tests are added to Appendix B. In the Johansen normalization report, the energy price index is positioned as the dependent variable. The results suggest that, in the long run, metal and mineral and fish price indices have a positive effect on energy prices while forest prices have a negative effect. The coefficients are statistically significant at the 1% level. Furthermore, the coefficient of the error correction term for metals and minerals, agriculture, fish, and forest are all statistically significant at the 1% level. This suggests that for those variables, the previous year's deviation from the long-run equilibrium is corrected for within the current year. Hence, there is evidence of both short-run and long-run relationships among the variables.

References

Chen, Y. C., Rogoff, K. S., & Rossi, B. (2010). Can exchange rates forecast commodity prices?. *The Quarterly Journal of Economics*, *125*(3), 1145-1194.

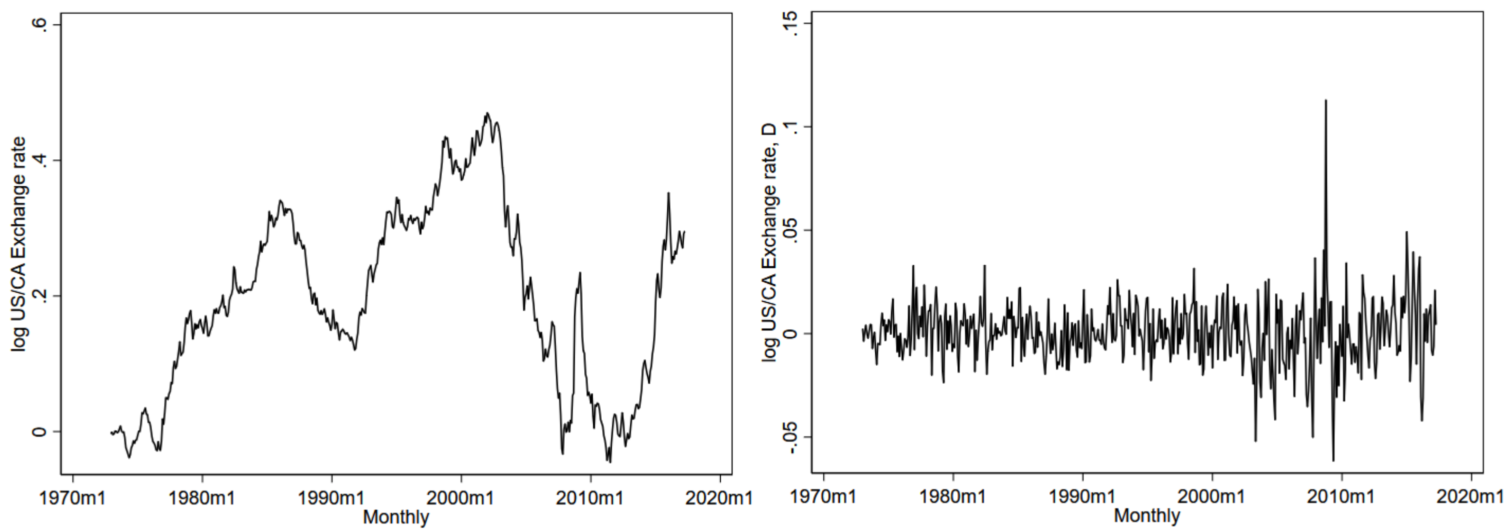
Liu, L., Tan, S., & Wang, Y. (2020). Can commodity prices forecast exchange rates?. *Energy Economics*, *87*, 104719.

Marinucci, D., & Robinson, P. M. (2001). Semiparametric fractional cointegration analysis. *Journal of Econometrics*, *105*(1), 225-247.

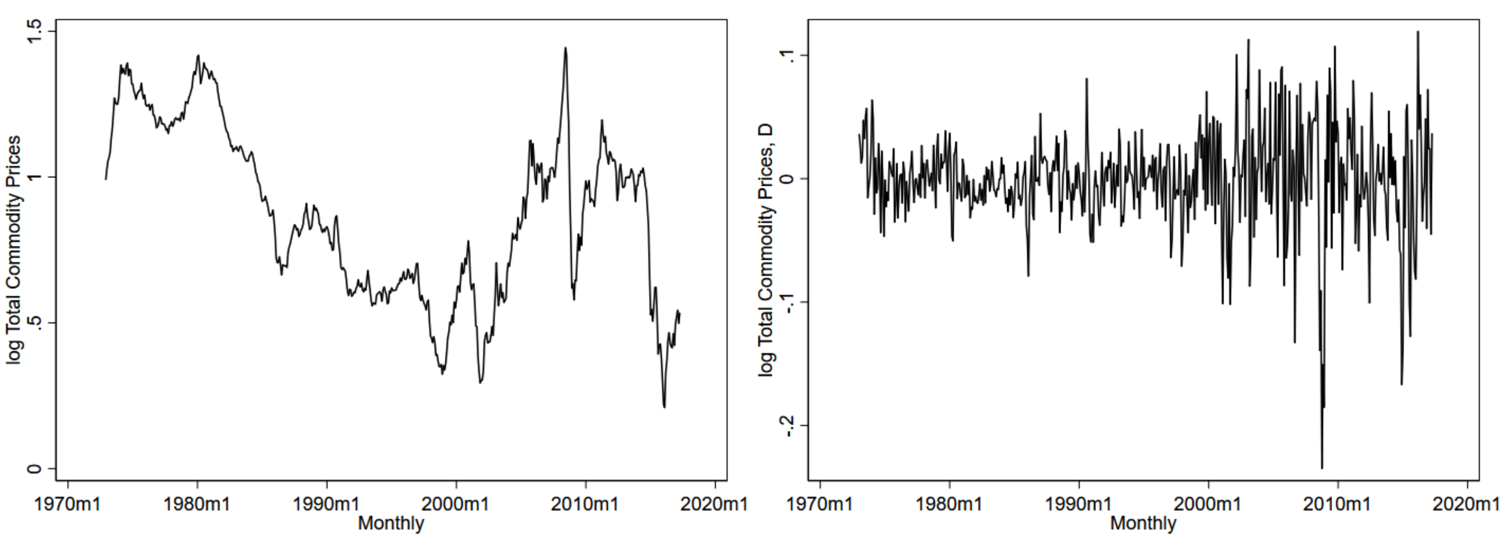
Appendix

Appendix A

Appendix A1: US-Canada Exchange rate at levels and at first difference



Appendix A2: Total Commodity Prices (Deflated, log) in levels and first difference.



Appendix A3: Correlation Matrix of US-Canada Exchange rate and Total Commodity Prices

Pairwise correlations

Variables	(1)	(2)
(1) lnexr	1.000	
(2) lnprice_real	-0.748	1.000
	(0.000)	

Pairwise correlations

Variables		
(1) D.lnexr	1.000	
(2) D.lnprice_real	-0.446	1.000
	(0.000)	

Appendix A4: Unit Root Tests

Lag Selection: Exchange rate

```
. varsoc lnexr

 Lag-order selection criteria

   Sample: 1973m4 thru 2017m4                              Number of obs = 529
```

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	313.834				.017942	-1.18274	-1.17958	-1.17466
1	1483.67	2339.7	1	0.000	.000216	-5.60177	-5.59545	-5.58562
2	1506.67	46.004*	1	0.000	.000199*	-5.68495*	-5.67547*	-5.66073*
3	1507.14	.94511	1	0.331	.000199	-5.68296	-5.67032	-5.65066
4	1507.15	.00669	1	0.935	.0002	-5.67919	-5.66339	-5.63882

```
   * optimal lag
   Endogenous: lnexr
    Exogenous: _cons
```

Lag Selection: Total Commodity Prices

```
. varsoc lnprice_real

Lag-order selection criteria

   Sample: 1973m4 thru 2017m4                            Number of obs = 529
```

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-99.4299				.085591	.379697	.382858	.387771
1	964.664	2128.2	1	0.000	.001538	-3.63956	-3.63324	-3.62341
2	988.72	48.112*	1	0.000	.001409	-3.72673	-3.71725*	-3.70251*
3	989.744	2.0489	1	0.152	.001409*	-3.72682*	-3.71418	-3.69453
4	989.792	.09446	1	0.759	.001414	-3.72322	-3.70742	-3.68285

```
   * optimal lag
   Endogenous: lnprice_real
    Exogenous: _cons
```

ADF Test: Exchange rate at levels with trend

```
. dfuller lnexr, lags(1) trend

Augmented Dickey-Fuller test for unit root

Variable: lnexr                          Number of obs  = 531
                                         Number of lags =   1

H0: Random walk with or without drift
```

	Test statistic	Dickey-Fuller critical value 1%	5%	10%
Z(t)	-1.886	-3.960	-3.410	-3.120

```
MacKinnon approximate p-value for Z(t) = 0.6619.
```

ADF Test: Exchange rate at first difference

```
. dfuller d.lnexr

Dickey-Fuller test for unit root          Number of obs  = 531
Variable: D.lnexr                         Number of lags =   0

H0: Random walk without drift, d = 0
```

	Test statistic	Dickey-Fuller critical value 1%	5%	10%
Z(t)	-17.160	-3.430	-2.860	-2.570

```
MacKinnon approximate p-value for Z(t) = 0.0000.
```

ADF Test: Total Commodity Prices at levels with trend

```
. dfuller lnprice_real, lags(2) trend

Augmented Dickey–Fuller test for unit root

Variable: lnprice_real                    Number of obs  = 530
                                          Number of lags =   2

H0: Random walk with or without drift

                                       Dickey–Fuller
                   Test      ──────── critical value ─────────
              statistic           1%           5%          10%
──────────────────────────────────────────────────────────────
 Z(t)            -2.542       -3.960       -3.410       -3.120
──────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.3073.
```

ADF Test: Total Commodity Prices at first difference

```
. dfuller d.lnprice_real, lags(1)

Augmented Dickey–Fuller test for unit root

Variable: D.lnprice_real                  Number of obs  = 530
                                          Number of lags =   1

H0: Random walk without drift, d = 0

                                       Dickey–Fuller
                   Test      ──────── critical value ─────────
              statistic           1%           5%          10%
──────────────────────────────────────────────────────────────
 Z(t)           -12.983       -3.430       -2.860       -2.570
──────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.0000.
```

Appendix A5: Cointegration Tests

Single-Equation Approach

Linear regression of Deflated Total Commodity Price Index on Exchange rate

lnprice_real	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnexr	-1.623	.062	-26.00	0	-1.746	-1.5	***
Constant	1.191	.015	80.57	0	1.162	1.22	***

Mean dependent var	0.874	SD dependent var	0.292
R-squared	0.560	Number of obs	533
F-test	676.031	Prob > F	0.000
Akaike crit. (AIC)	-236.074	Bayesian crit. (BIC)	-227.517

*** *p<.01, ** p<.05, * p<.1*

Johansen Test

```
. vecrank lnprice_real lnexr, lags(3)

Johansen tests for cointegration
Trend: Constant                                 Number of obs  = 530
Sample: 1973m3 thru 2017m4                      Number of lags =   3
-------------------------------------------------------------------------------
                                                                 Critical
Maximum                                                Trace        value
   rank   Params          LL   Eigenvalue   statistic           5%
      0       10   2553.5085            .      10.6046*        15.41
      1       13   2556.8952      0.01270       3.8314          3.76
      2       14   2558.8109      0.00720
-------------------------------------------------------------------------------
* selected rank
```

Appendix A6: Vector Autoregressive Model

Lag Selection

```
. varsoc dlnprice_real dlnexr, exo(time)
```

Lag-order selection criteria

Sample: 1973m5 thru 2017m4 Number of obs = 528

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	2499.57				2.7e-07	-9.45293	-9.44027	-9.42059
1	2538.14	77.133*	4	0.000	2.4e-07	-9.58387	-9.55854*	-9.51918*
2	2542.33	8.3724	4	0.079	2.4e-07*	-9.58457*	-9.54659	-9.48755
3	2543.42	2.178	4	0.703	2.4e-07	-9.57355	-9.5229	-9.44418
4	2547.8	8.7696	4	0.067	2.4e-07	-9.575	-9.5117	-9.4133

Estimation of the Vector Autoregressive Model

```
. var d.lnprice_real d.lnexr, exo(time) lags(1/2)

Vector autoregression

Sample: 1973m3 thru 2017m4                        Number of obs     =        530
Log likelihood =   2553.769                       AIC               =  -9.591581
FPE            =   2.34e-07                       HQIC              =  -9.553714
Det(Sigma_ml)  =   2.24e-07                       SBIC              =  -9.494837

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
D_lnprice_real        6     .037464   0.0926   54.08193   0.0000
D_lnexr               6     .014061   0.0913   53.27988   0.0000
----------------------------------------------------------------

--------------------------------------------------------------------------------
               | Coefficient  Std. err.      z    P>|z|     [95% conf. interval]
---------------+----------------------------------------------------------------
D_lnprice_real |
  lnprice_real |
           LD. |   .2507374   .0476329     5.26   0.000     .1573787    .3440961
          L2D. |   .0209526   .0476604     0.44   0.660    -.0724602    .1143653
               |
         lnexr |
           LD. |  -.1174411   .1268383    -0.93   0.354    -.3660395    .1311573
          L2D. |  -.1826277   .1267736    -1.44   0.150    -.4310995     .065844
               |
          time |  -2.81e-06   .0000106    -0.27   0.791    -.0000236    .0000179
         _cons |   .0006359   .0047606     0.13   0.894    -.0086947    .0099665
---------------+----------------------------------------------------------------
D_lnexr        |
  lnprice_real |
           LD. |  -.0317899   .0178776    -1.78   0.075    -.0668293    .0032496
          L2D. |  -.0136094   .0178879    -0.76   0.447    -.0486691    .0214503
               |
         lnexr |
           LD. |   .2586853    .047605     5.43   0.000     .1653813    .3519894
          L2D. |  -.0681205   .0475807    -1.43   0.152     -.161377     .025136
               |
          time |  -1.98e-06   3.98e-06    -0.50   0.618    -9.77e-06    5.81e-06
         _cons |   .0012539   .0017868     0.70   0.483    -.0022481    .0047559
--------------------------------------------------------------------------------
```

Appendix A7: Residual Diagnostics Tests

Autocorrelation

Lagrange-multiplier test

lag	chi2	df	Prob > chi2
1	1.6733	4	0.79556
2	6.1067	4	0.19132

H0: no autocorrelation at lag order

Normality Tests

```
. varnorm, jbera skewness kurtosis
```

Jarque-Bera test

Equation	chi2	df	Prob > chi2
D_lnprice_real	201.636	2	0.00000
D_lnexr	186.818	2	0.00000
ALL	388.455	4	0.00000

Skewness test

Equation	Skewness	chi2	df	Prob > chi2
D_lnprice_real	-.45623	18.386	1	0.00002
D_lnexr	.21235	3.983	1	0.04596
ALL		22.370	2	0.00001

Kurtosis test

Equation	Kurtosis	chi2	df	Prob > chi2
D_lnprice_real	5.8806	183.250	1	0.00000
D_lnexr	5.8774	182.835	1	0.00000
ALL		366.085	2	0.00000

Appendix A8: Granger-Causality Test

```
. regress dlnexr time L(1/2).dlnexr L(1/2).dlnprice_real

      Source |       SS           df       MS      Number of obs   =       530
-------------+----------------------------------   F(5, 524)       =     10.54
       Model |  .010414821         5  .002082964   Prob > F        =    0.0000
    Residual |   .10360112       524  .000197712   R-squared       =    0.0913
-------------+----------------------------------   Adj R-squared   =    0.0827
       Total |   .11401594       529  .000215531   Root MSE        =    .01406

------------------------------------------------------------------------------
      dlnexr | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
        time |  -1.98e-06   4.00e-06    -0.50   0.620    -9.84e-06    5.87e-06
             |
      dlnexr |
         L1. |   .2586853   .0478767     5.40   0.000     .1646314    .3527393
         L2. |  -.0681205   .0478524    -1.42   0.155    -.1621265    .0258855
             |
dlnprice_r~l |
         L1. |  -.0317899   .0179796    -1.77   0.078    -.0671109    .0035312
         L2. |  -.0136094   .0179901    -0.76   0.450    -.0489509     .021732
             |
       _cons |   .0012539    .001797     0.70   0.486    -.0022762     .004784
------------------------------------------------------------------------------

. test (L.dlnprice_real) (L2.dlnprice_real)

 ( 1)  L.dlnprice_real = 0
 ( 2)  L2.dlnprice_real = 0

       F(  2,   524) =    2.27
            Prob > F =    0.1046
```

```
. regress dlnprice_real time L(1/2).dlnexr L(1/2).dlnprice_real

      Source |       SS           df       MS      Number of obs   =       530
-------------+----------------------------------   F(5, 524)       =     10.69
       Model |   .07504758         5  .015009516   Prob > F        =    0.0000
    Residual |  .735462212       524  .001403554   R-squared       =    0.0926
-------------+----------------------------------   Adj R-squared   =    0.0839
       Total |  .810509792       529  .001532155   Root MSE        =    .03746

------------------------------------------------------------------------------
dlnprice_r~l | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
        time |  -2.81e-06   .0000107    -0.26   0.792    -.0000237    .0000181
             |
      dlnexr |
         L1. |  -.1174411   .1275624    -0.92   0.358    -.3680376    .1331554
         L2. |  -.1826277   .1274974    -1.43   0.153    -.4330965    .0678411
             |
dlnprice_r~l |
         L1. |   .2507374   .0479048     5.23   0.000     .1566283    .3448464
         L2. |   .0209526   .0479325     0.44   0.662     -.073211    .1151161
             |
       _cons |   .0006359   .0047878     0.13   0.894    -.0087697    .0100415
------------------------------------------------------------------------------

. test (L.dlnexr) (L2.dlnexr)

 ( 1)  L.dlnexr = 0
 ( 2)  L2.dlnexr = 0

       F(  2,   524) =    1.82
            Prob > F =    0.1626
```

Appendix B

Unit Root Tests

Energy

```
. dfuller lnenergy, lags(1) trend

Augmented Dickey-Fuller test for unit root

Variable: lnenergy                          Number of obs  = 531
                                            Number of lags =   1

H0: Random walk with or without drift
```

	Test statistic	Dickey-Fuller critical value 1%	5%	10%
Z(t)	-2.979	-3.960	-3.410	-3.120

MacKinnon approximate *p*-value for Z(t) = 0.1380.

Metals and Minerals

```
. dfuller lnmetmin, lags(1) trend

Augmented Dickey-Fuller test for unit root

Variable: lnmetmin                          Number of obs  = 531
                                            Number of lags =   1

H0: Random walk with or without drift
```

	Test statistic	Dickey-Fuller critical value 1%	5%	10%
Z(t)	-2.617	-3.960	-3.410	-3.120

MacKinnon approximate *p*-value for Z(t) = 0.2722.

Agriculture

```
. dfuller lnagric, lags(3) trend

Augmented Dickey–Fuller test for unit root

Variable: lnagric                           Number of obs  = 529
                                            Number of lags =   3

H0: Random walk with or without drift

                                       Dickey–Fuller
                   Test     ———————— critical value ————————
              statistic           1%           5%          10%
————————————————————————————————————————————————————————————————
 Z(t)            -2.943       -3.960       -3.410       -3.120
————————————————————————————————————————————————————————————————
MacKinnon approximate p-value for Z(t) = 0.1486.
```

Fish

```
. dfuller lnfish, lags (3) trend // trend stationary

Augmented Dickey–Fuller test for unit root

Variable: lnfish                            Number of obs  = 529
                                            Number of lags =   3

H0: Random walk with or without drift

                                       Dickey–Fuller
                   Test     ———————— critical value ————————
              statistic           1%           5%          10%
————————————————————————————————————————————————————————————————
 Z(t)            -5.528       -3.960       -3.410       -3.120
————————————————————————————————————————————————————————————————
MacKinnon approximate p-value for Z(t) = 0.0000.
```

Forest

```
. dfuller lnforest, lags (2) trend // trend stationary

Augmented Dickey–Fuller test for unit root

Variable: lnforest                          Number of obs  = 530
                                            Number of lags =   2

H0: Random walk with or without drift

                                       Dickey–Fuller
                   Test     ———————— critical value ————————
              statistic           1%           5%          10%
————————————————————————————————————————————————————————————————
 Z(t)            -3.818       -3.960       -3.410       -3.120
————————————————————————————————————————————————————————————————
MacKinnon approximate p-value for Z(t) = 0.0157.
```

Lag selection for VECM

```
. varsoc lnenergy lnmetmin lnagric lnfish lnforest, exo(time) // lags 2
```

Lag-order selection criteria

Sample: 1973m4 thru 2017m4 Number of obs = 529

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	665.141				5.8e-08	-2.4769	-2.4453	-2.39617
1	4159.4	6988.5	25	0.000	1.2e-13	-15.5932	-15.4826	-15.3106
2	4248.44	178.08	25	0.000	9.1e-14*	-15.8353*	-15.6457*	-15.3509*
3	4268.09	39.298*	25	0.034	9.3e-14	-15.8151	-15.5465	-15.1288
4	4278.63	21.069	25	0.689	9.8e-14	-15.7604	-15.4128	-14.8723

* optimal lag
Endogenous: lnenergy lnmetmin lnagric lnfish lnforest
Exogenous: time _cons

VEC Model

Cointegrating equations

Equation	Parms	chi2	P>chi2
_ce1	4	57.33452	0.0000

Identification: beta is exactly identified

Identification: beta is exactly identified

Johansen normalization restriction imposed

beta	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
_ce1						
lnenergy	1	.	.	.	.	.
lnmetmin	-1.752944	.6499499	-2.70	0.007	-3.026822	-.4790654
lnagric	1.312603	.9902675	1.33	0.185	-.628286	3.253491
lnfish	-2.329644	.4041386	-5.76	0.000	-3.121741	-1.537547
lnforest	6.14346	1.008929	6.09	0.000	4.165995	8.120925
_cons	-22.58984	.	.	.	.	.