# Price Transmission Channels of

# Energy and Exchange Rate on Food Sector

# : A Disaggregated Approach based on Stage of Process

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## ABSTRACT

The recent concurrent surges of food and energy prices renew our interest on the vulnerability of food system to sudden changes in the energy sector. Unlike previous studies focusing on the impacts of a single energy price on food sector, this study explores such dependency utilizing various food and energy prices classified by stage of processing. Based on the method proposed by Toda and Yamamoto (1995) and Dolado and Lütkepohl (1996) of Granger causality tests, we identify how the movements of the exchange rate and the various energy prices affect on the food prices from farmers to consumers.


## INTRODUCTION

The United States (U.S.) economy heavily depends on energy consumption. The overall food system, from farmers to consumers, is not an exception. According to the Earth Policy Institute, the U.S. food system uses over 10 quadrillion Btu (10,551 quadrillion Joules) of energy each year, which is as much as France's annual energy consumption and comprises about 10% of the total U.S. energy consumption (Murray, 2005). In addition to the agricultural production, the overall food processing and distribution systems also heavily rely on the energy sector. For example, Heller and Keoleian (2000) suggest that almost 41% is used in the processing and distribution system (14% goes to food transport, 16% to processing, 7% to packing, and 4% to food retailing) and 32% is used to home refrigeration and preparation,[1] while approximately 21% of the total energy consumption in the food system is used in agricultural production.

Despite such dependency of the food system on energy consumption, the energy price usually had been relatively low enough not to raise public concerns, except the oil price surge in the early 1970s and 1980s. For example, oil prices were roughly $20 per barrel during most of the 1990s and energy costs were smaller share of production costs and consumer budget than 1970s-80s (Bernanke, 2004). However, the heavy dependency of the food system on the energy sector is demonstrated through the consequence vulnerability of the food system to sudden changes in the energy sector in several occasions, including the recent food inflation phenomenon.[2]

Various studies are conducted to examine the effect of energy price fluctuation on the economy. In the literature on the nexus between oil price and macroeconomy, numerous studies provide empirical evidences that rising oil prices slow economic growth and stimulate inflation, and also identify various channels through which energy price fluctuations affect the overall economy (e.g., Brown and Yücel 2002, Jones, Leiby, and Paik 2004 and references in there). For example, Hamilton (1983) demonstrated that oil price shock had proceeded all but one recession in the terms of Granger causality. Such findings made a definitive contribution to expanding researchers' attention to the entire period beyond several occasions of oil price shocks.

In the study regarding the impact of energy price on the agricultural sector, Hanson, Robinson, and Schluter (1993), among others, use Computable General Equilibrium (CGE) model to analyze the direct and indirect cost linkages among three energy sectors (crude oil and gas, petroleum refining, and electric and gas utilities) and various agricultural production and processing sectors. Under the scenario that the high oil price results in a depreciation of the dollar, which in turn stimulates agricultural exports, they show that the rising energy and agricultural prices result in the increased consumer food prices. In the investigation on price linkage of oil and commodity prices, Baffes (2007) find that the price indexes for fertilizer and food commodities exhibit the highest pass-through of oil price changes among the various non-energy commodity indexes, based on annual data from 1960 to 2005.

In this study, we aim to identify the transmission mechanism of energy prices on overall food prices. For that purpose, three kinds of energy prices and four different kinds of food prices are adopted based on the stage of process (SOP) system classified by the Bureau of Labor Statistics (BLS). The main motivation is that diverse kinds of energy can affect the overall food system at various stages in a number of different ways. For example, the 34% of energy use in agricultural production is directly consumed as diesel and gasoline by farm vehicles for planting, tilling, and harvesting. On the other hand, the 35% is indirectly used in the form of fertilizer and pesticides, which are manufactured from natural gas and petroleum[3] (Murray 2005). Beyond agricultural production, food processing and packing sectors use 23% of various kinds of energy consumed in the food system as the proliferation of processed food with small packages requires various energy consumptions. In addition, as food production is concentrated in specific areas in a country and around world, the U.S. foodstuff travels an average of 1,500 miles before being consumed in numerous ways (Heller and Keoleian, 2000).

Our approach is distinct from previous literature and contributes the literature on price linkages between energy and food sectors in several ways. First, while previous studies focused on the single measure of energy price such as the crude oil price, this study uses diverse energy prices classified by the SOP system of producer price index (PPI) incorporating crude, intermediate, and finished stages. By using more disaggregated information than previous literature, we can obtain more detailed information on the energy-food price transmission mechanism.

Second, we explore the effects of energy price on the overall food sectors, covering processing and distributional systems not only the agricultural production, focused in the previous studies. The SOP system is further extended to integrate consumer price index (CPI) for food at home to examine the recent food inflation phenomenon at retail level.[4] The use of broad food prices from crude, intermediate, finished, and retail stages allow us to investigate whether the recent food inflation is derived by the cost-push (e.g., Engel 1978) or demand-pull mechanism (e.g., Granger, Robinsons and Engle 1986).

Third, our analysis incorporates the exchange rate in analyzing the relationship between energy and food prices. Under the global economy, it is plausible that the high oil price can result in depreciation of the U.S. dollar, which in turn stimulate agricultural exports and hence boost food prices (e.g. Hanson, Robinson, and Schluter 1993). It is also observed that the depreciation of the U.S. dollar is one of key factors contributing to the recent food inflation (e.g. Abbott, Hurt, and Tyner 2008). By incorporating the exchange rate, we can further investigate whether the exchange rate affects the energy price due to denomination effect of the U.S. dollar (e.g., Zhang, Fan, Tsai, and Wei 2008) or vice versa because of the impact of the energy price on current account (e.g., Chen and Chen 2007).

Finally, given that our objective is not detecting the presence/absence of unit roots or possible long-run (cointegrating) relationships but testing Granger causality of the possible cointegrated VAR (Vector Autoregressive) models, we adopt the method proposed by Toda and Yamamoto (1995) and Dolado and Lütkepohl (1996) (TYDL). The recent time-series studies (e.g., Yamada and Toda 1998, Giles and Mirza 1999, and Clarke and Mirza 2006) demonstrate robustness of the TYDL approach over a wide range of stationary, near-integrated, and cointegrated systems, compared to some drawbacks of the vector error correction model (VECM) or fully modified VAR methods.

## EMPIRICAL MODEL

Given the heavy dependence of food sector on energy consumption, the food price ( $PF_t$ ) can be expressed as a function of energy price ( $PE_t$ ) and other factors ( $Z_t$ ) as:

(1) $PF_t = f(PE_t, Z_t)$.

The main objective of this study is to identify the price transmission channels of energy on food at various stages of process. For this purpose, we dissect each sector into the sequential input-output stages of process and introduce subscript $i$ and $j$ to represent each stage of process. The food sector is disaggregated into four groups such as crude, intermediate, finished, and retail stages ( $i = 1, 2, 3,\ and\ 4$ ). Similarly, the energy sector is also classified into three groups such as crude, intermediate, and finished stages ( $j = 1, 2,\ and\ 3$ ). Thus, the equation (1) can be written more specifically as:

(2) $PF_{i,t} = f(PE_{j,t}, Z_t)$, where $i = 1, 2, 3,\ and\ 4$ and $j = 1, 2,\ and\ 3$.

Important candidates ( $Z_t$ ) to be considered in determining food price at certain stage of process are the other food prices at different stages of process. However, there has been long history of debate between cost-push and demand-pull arguments to specify the relationships. For example, the cost-push view argues that change of the crude food price ( $-i$ ), as input cost, pushes the movement of the intermediate food price ( $i$ ) (e.g., Engel 1978, and Silver and Wallace 1980). On the other hand, the demand-pull view claims that variation of finished food price ( $+i$ ), as derived demand, pulls the movement of the intermediate food price ( $i$ ) (e.g., Colclough and Lange 1982, and Granger, Robinsons and Engle 1986). In this respect, the equation (2) can be further rewritten as:

(3) $PF_{i,t} = f(PE_{j,t}, PF_{-i,t}),\ \forall\ i = 2,3,\ and\ 4$ or $PF_{i,t} = f^{'}(PE_{j,t}, PF_{+i,t}), \forall\ i = 1,2,\ and\ 3$ .

Furthermore, to assess the possible linkages of exchange rate with energy and/or food prices, the exchange rate need be incorporated in analyzing the relationship between energy and food prices. However, there exists another important issue for the specific transmission channel from exchange rate on the food price. For example, one group claims that the exchange rate affect the energy price based on the denomination effect of the U.S. dollar (e.g., Zhang et al 2008 and Abbott, Hurt, and Tyner 2008). On the other hand, the other group argues that the high oil price, through the impact on the current account, can result in depreciation of the U.S. dollar, which in turn stimulate agricultural exports and boost food prices (e.g., Hanson, Robinson, and Schluter 1993 and Chen and Chen 2007). These different views can be expressed as

(4) $PE_{j,t} = g(ER_t)$ or $ER_t = g^{'}(PE_{j,t})$

Given that there can be lots of possible combinations of equations (3) and (4), it is clear that economic theory does not provide sufficient information of the causal structures among energy price, exchange rate, and food price. In this respect, we empirically pursue to identify the transmission channels of energy price and exchange on food price in this study.

## ECONOMETRIC PROCEDURE

The Granger causality (Granger 1969) is the most common concept for causality analysis in literature[5]. For example, Hamilton (1983) established relationships between energy price and macroeconomic variables based on the Granger non-causality (GNC) test. For empirical analysis, the VECM is frequently used when cointegration is suspected.[6] However, since (i) GNC test in

VECM involves the nonlinearity on $\Pi = \alpha\beta$, where $\beta$ represents cointegrating vector and $\alpha$ captures the speed of adjustment to such long-run relationship, and (ii) the asymptotic distribution of test statistics can be non-standard and may involve nuisance parameters unless the data meet the certain rank condition of submatrices in the cointegration space, which is not always satisfied under the null hypotheses (Toda and Phillips 1993). [7] In this respect, Toda and Phillips (1993) suggest a sequential test procedure involving non-stationary, cointegration, and rank condition of certain submatrices in the cointegration space. However, such pretesting strategy has unknown overall properties with generally low statistical power, can leave the possibility to chose the inappropriate model for GNC test and lead to the misleading conclusion for GNC. Such possibilities are demonstrated by several simulation studies (e.g., Yamada and Toda 1998, Giles and Mirza 1999, Clarke and Mirza 2006).

To address this issue, Toda and Yamamoto (1995) and Dolado and Lutkepohl (1996) (TYDL, hereafter) demonstrate that (i) given the nonstandard asymptotic properties of the test statistics are due to the singularity of the asymptotic distribution of the LS estimator, the main issue is to find alternative, which result in a nonsingular asymptotic distribution of the relevant estimator to overcome the complicated nonstandard limiting properties and (ii) the singularity in a nonstationary system can be removed by fitting a augmented VARL model. Its order exceeds the true order by the highest degree of integration in the system as follows:

(5) $Z_t = \sum_{i=1}^{k} \Phi_i Z_{t-i} + \sum_{j=1}^{d} \Phi_{k+j} Z_{t-k-j} + \varepsilon_t \,, \qquad H_0 : R_M \; vec(\Phi_1, \cdots, \Phi_k) = 0 \,,$

where $k$ is the true lag length, $d$ is the maximal order of integration among variables in the system, $vec(\cdot)$ represents to stack the row of a matrix in a column vector, $R_M$ is the appropriate selection vector corresponding to a specific GNC hypothesis and $z_t$ is vector of exchange rate and disaggregated energy and food prices based on the SOP system. TYDL further prove that (iii) the hypothesis can be tested based on asymptotic $\chi^2$ distribution by using modified Wald statistics while ignoring the coefficient matrix of the augmented lag in the estimated equation, which is a zero matrix by assumption, and (iv) it is valid to use the commonly used lag length selection procedure such as the general-to-specific method, based on sequential Likelihood Ratio (LR) test.

Although there exist efficiency and power loss by augmenting extra lags, recent simulation studies (e.g., Yamada and Toda 1998, Giles and Mirza 1999, Clarke and Mirza 2006) demonstrate that (i) the TYDL method is better control the type I error probability than other methods based on the VARL, VARD, and VECM, (ii) the power loss in the TYDL approach is relatively minor for moderate and large sample sizes, and (iii) the TYDL approach results in a consistent performance over a wide range of systems, including stationary, near-integrated, and cointegrated systems, even for the mixed integrated systems [8]. Consequently, the recent time-series literature (e.g., Yamada and Toda 1998, Giles and Mirza 1999, Clarke and Mirza 2006) recommends to use the TYDL approach, when the research objective is not detecting the presence (or absence) of unit roots or possible long-run (cointegrating) relationships but testing Granger causality of the possible cointegrated VAR models with I(0) /I(1) variables. This study follows this recommendation to investigate causal relationships among various energy and food prices.

## DATA DESCRIPTION

To trace the impacts of various energy prices on the food prices at different stages of process, we collect several price indexes based on the SOP system from January 1998 to July

2008: the PPI indexes of crude energy goods (denoted by CE), intermediate energy goods (IE), finished energy goods (FE), crude foodstuffs and feedstuffs (CF), intermediate foods and feeds (IF), and finished consumer foods (FF), and Consumer Price Index of food at home (HF). According to BLS, the coverage of each index is as follows: crude petroleum, natural gas, coal, etc. for CE; diesel fuel, industrial natural gas, commercial electric power, etc. for IE; gasoline, residential natural gas, residential electric power, etc. for FE; wheat, corn, soybeans, fluid milk, etc. for CF; flour, prepared animal feeds, fluid milk products, etc. for IF; pork, dairy products, processed fruits and vegetables, etc. for FF. The CPI index for food at home represents the food price at retail level, which encompasses the similar product coverage of PPI index for the finished food. All data are seasonally adjusted and log transformed. The real effective exchange rate variable (ER) from International Monetary Fund (IMF) is also incorporated to investigate the claimed nexus of exchange rate with energy and/or food prices as discussed.

When the oil price shocks occurred in 1973-74, the Bureau of Labor Statistics (BLS) published the Wholesale Price Index (WPI) based on the All Commodities aggregation. However, this aggregation was based on the inappropriate weight schemes and thus overstated the inflation rate due to the multiple counting problems. Furthermore, the WPI include the full range of items irrespective of their degree of fabrications and thus mask or distort the analyses of the actual price transmission mechanism. For example, the crude oil price increase was multiplied as it passed through various stages of process, as the high energy prices at given stage were embodied in the price of next stage of process along the sequential series of input-output cost structures (Gaddie and Zoller 1988). To address this issue, the BLS shift the analytical focus from the All Commodities Price Index to the Producer Price Index (PPI) based on the commodity-based stages of processing (SOP) price indexes since 1978 (BLS 2008).

The definition and purpose of the SOP system is clearly explained by Gaddie and Zoller (1988) as follows: "the basic idea of a stage of process system is that the economy can be subdivided into distinct economic segments which can be arranged sequentially so that the outputs of earlier segments become inputs to subsequent ones, up through final demand. As a simple example, one economic sector may produce wheat, which is input to another that produces flour, which is input to another that produces bread. To the extent that such a sequential system of processing stages can be defined, it is possible to trace the transmission of price change through the economy and to develop information on both the timing and magnitude of price passthroughs to final demand (page 4)."

This methodological shift of the BLS is utilized in this study to investigate the multifarious price impacts of various kinds of energy on the overall food system. In this respect, our approach is different from previous studies, which are focused on impacts of the single energy price measure such as the crude oil price, as discussed.

## EMPIRICAL RESULTS

### *Preliminary Analysis*

The main objective of this study is to understand how various energy prices affect the food prices at different stages of process, not vice versa. In this respect, to avoid the multicollinearity problem among the crude, intermediate, and finished energy prices, we develop three cases. The case I incorporates relationship between the crude energy price and the crude, intermediate, finished food price indexes and exchange rate variable. And the case II (and III) encompasses the relationship between the intermediate (finished) energy price index with the common variables of the food prices at various stages of process and the exchange rate.

Following Toda and Yamamoto (1995), the general-to-specific method, based on sequential Likelihood Ratio (LR) test, is applied to determine appropriate lag length. For the case I, the hypothesis test of reduction of lag length from 3 to 2 results in a LR test statistic of 53.555 with a p-value of 0.03, while those from 2 to 1 are 85.102 and 0.00, respectively. Diagnostic statistics of the Lagrange Multiplier (LM) test for the absence of auto-correlation in residual show that the p-value of LM test for order 1 (and 2) are 0.32 (and 0.05) for the two lag length VAR specification. For the case II (and III), the LR test statistic is 46.999 with p-value 0.10 (45.865 with 0.13) for lag length reduction from 3 to 2, while those from 2 to 1 are 87.350 and 0.00 (83.426 and 0.00), respectively. The p-values of LM tests against order 1 and 2 are 0.20 and 0.13 (0.49 and 0.14) for two lag length specification in the case II (and III). These results suggest that lag length of two is appropriate for the subsequent analyses without concern for the autocorrelation problem for all the three cases.

***Price Transmission Mechanism within the Food System***

Based on the above results, the Granger non-causality (GNC) tests are conducted based on the TYDL method, using the two lag length specification and assuming maximum integration order of one. The modified Wald statistics and p-values are reported in Tables 1, 2, and 3 for cases I, II, and III, respectively. The identified causal flows in Granger sense in Tables 1, 2, and 3 are summarized in the corresponding Figures 1, 2, and 3. In addition, the overall causal structure we might draw from the overall results of three cases is recapitulated in Figure 4. In Figures 1-4, each (and dotted) arrow represents the identified causal flow at least 5% (and 10%) significant level in Granger sense, given that the p-value of less than 5% indicates rejection of the null hypothesis of Granger non-causality at the 95% confidence level.

The identified price transmission mechanism within the food system is quite robust with regard to the variations among the three cases. The crude (and finished) food price Granger causes the intermediate food (home food) price at the 1% significance level. Despite the absence of causal link between the intermediate food and the finished food prices, the causal flow from crude to finished food prices and causal relationship from intermediate to home food prices connect the overall cost-push mechanism at least 6.1% significance level. Such results can be explained by the facts that the intermediate stage is defined as residuals after defining the crude and finished stage (BLS 2008). As Gaddie and Zoller (1988) pinpoint, part of output at a given stage of process can be used by stages of process beyond the next sequential stage of process (skip mechanism in SOP system), since the complicated industrial relationships preclude the clear division of goods into three stages. Considering such aspects, the non-robust results of the demand-pull mechanism from the intermediate to crude food prices can be also explained, given that causal relationship is statistically significant only at the 9.9% significant level in the case I.

The identified cost-push transmission mechanism (Figure 4) is consistent to several studies (e.g., Boyd and Brorsen 1985, Goodwin and Holt 1999, and Goodwin and Harper 2000), which show the price transmission mechanism from farm to wholesale to retail market for a specific commodity such as pork or beef. On the other hand, our results identify more detailed price transmission channels and reveal the cost-push mechanism along the sequential stages of process with some skip mechanisms. These finding can contribute to understand the recent food inflation phenomenon, by provide empirical evidences of the notion that the increase of farm commodity prices is large enough to affect retail food prices, despite the small portion of agricultural commodity values in retail food prices (e.g., Abbott, Hurt, and Tyner 2008).

***Linkages of Energy prices and Exchange rate with Food Prices***

The effects of the energy price and exchange rate on the food price at the retail level are another common aspect to the various analyses for the recent food inflation, as discussed. In this respect, our results provide empirical evidences such that (i) the crude energy price Granger causes the crude food price at about 1% significance level (Table 1), (ii) the intermediate energy price causes the crude food price at the 1% significance level, the finished food price at the 5% significance level, and the intermediate and home food prices at the 10% significance level (Table 2), (iii) the finished energy price leads the crude and home food prices at the 5% significance level and the intermediate food price at the 10% significance level (Table 3).

The results are consistent with the previous findings (e.g., Reed, Hanson, Elitzak, and Schluter 1997, Baffes 2007) for the heavy dependence of food sector on energy consumption. The crude, intermediate, and finished energy prices significantly affect the crude food price at least 3.5% (1.3%, 0.5%, and 3.5%, respectively) significance level, whose effects are transmitted to all the food prices at the various stages of process through the cost-push mechanisms within the food system. In addition, our results further identify the heterogeneous paths of energy and food price linkages at various stages of process. The intermediate (finished) energy price Granger causes the finished (home) food price at the 4.3% (2.4%) significance level, which are analogical to the forward sequential input-output relationship in the SOP system. The complex interdependencies and/or the difficulties in defining the intermediate stage also results in the impacts of the intermediate energy price on the intermediate and finished food prices and the effects of the finished energy price on the intermediate food price.

With the multifarious causal relationships between energy and food prices, the results show that the intermediate energy price Granger causes the exchange rate at the 1.2%

significance level, while the crude energy price is caused by the exchange rate at the 6.5% significance level (Table 1 and 2). The identified linkages of exchange rate with energy and/or food prices provide additional empirical evidence to understand the recent food inflation phenomenon. For example, Abbott, Hurt, and Tyner (2008) argue that the depreciating dollar is related with the over half of the crude oil price increases, because most commodities such as crude oil are denominated in the U.S. dollars, but are purchases in the local currency. They further claim that the link between the U.S. dollar and commodity prices is more important than many other studies imply, since the high oil prices can bring expanding current account deficits, which in turn bring depreciating currency especially when the large trade deficits exist. Our findings are also consistent with previous literature on the nexus of energy price and the exchange rate (e.g., Amano and Norden 1998, Chaudhuri and Daniel 1998, and Chen and Chen 2007). For example, Chen and Chen (2007) show that the real oil prices contribute significant forecasting power for real exchange rate movements based on the panel cointegration analysis.

## CONCLUDING REMARKS

This study explores the price transmission channels of energy prices and exchange rate on food prices. Unlike previous studies focusing on the impacts of a single energy price such as crude oil price, our analysis is based on the disaggregated information based on the various stage of process (SOP). By utilizing the TYDL method of Granger causality tests, we identify how the movements of the exchange rate and the various energy prices affect on the food prices at different stages of process from farmers to consumers.

The overall findings can be summarized as follows. First, the crude (and finished) food price Granger causes the intermediate food (retail food) price. The causal flow from crude (and intermediate) to finished (home) food prices connects the overall cost-push mechanism, despite the absence of causal link between the intermediate and the finished food prices. Overall results provide detailed information on price transmission channels and reveal the cost-push mechanism along the sequential stages of process with some skip mechanisms.

Second, the crude, intermediate, and finished energy prices significantly affect the crude food price, whose effects are transmitted to all the food prices at the various stages of process through the cost-push mechanisms within the food system. In addition, we identify the heterogeneous paths of energy and food price linkages at various stages of process. The intermediate (and finished) energy price Granger causes the finished (retail) food price, which are analogical to the forward sequential input-output relationship in the SOP system.

Finally, with the multifarious causal relationships between energy and food prices, the identified linkages of exchange rate with energy and/or food prices provide additional empirical evidence to understand the recent food inflation phenomenon. The intermediate energy price Granger causes the exchange rate, while the crude energy price is caused by the exchange rate. For example, Abbott, Hurt, and Tyner (2008) argue that the depreciating dollar is related with the over half of the crude oil price increases, because the crude oil is denominated in the U.S. dollars. They also claim that the high energy prices can bring expanding current account deficits, which in turn bring depreciating currency especially when the large trade deficits exist. In this respect, our findings provide empirical evidences of causal mechanisms among the causes of the recent surge of food prices identified by previous studies, contributing to understand how the recent food inflation phenomenon happens.

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Table 1. Modified Wald Test Result for Case I

| Dependent Variable | CE | CF | IF | FF | HF | ER |
|---|---|---|---|---|---|---|
| CE | - | 1.354 | 1.096 | 2.150 | 2.822 | 5.464* |
| | - | 0.508 | 0.578 | 0.341 | 0.244 | 0.065* |
| CF | 8.661** | - | 4.629* | 0.762 | 0.454 | 1.576 |
| | 0.013** | - | 0.099* | 0.683 | 0.797 | 0.455 |
| IF | 1.998 | 11.532*** | - | 1.134 | 1.551 | 0.563 |
| | 0.368 | 0.003*** | - | 0.567 | 0.460 | 0.755 |
| FF | 2.222 | 5.610* | 3.660 | - | 0.834 | 1.825 |
| | 0.329 | 0.061* | 0.160 | - | 0.659 | 0.402 |
| HF | 3.445 | 2.834 | 11.566*** | 28.921*** | - | 1.894 |
| | 0.179 | 0.242 | 0.003*** | 0.000*** | - | 0.388 |
| ER | 3.720 | 0.348 | 0.771 | 0.096 | 0.452 | - |
| | 0.156 | 0.840 | 0.680 | 0.953 | 0.798 | - |

Note: CE, IE, FE, CF, IF, FF, HF, and ER denote the PPI index of crude energy and intermediate energy, finished energy, crude foodstuffs and feedstuffs, intermediate foods and feeds, and finished consumer foods, and CPI indexes of food at home, and Exchange Rate, respectively. The asterisks of ***, **, and * represent statistically significant at 1, 5, and 10 %, respectively. For each cell, first and second number is $\chi^2$ and corresponding p-value, respectively.

Table 2. Modified Wald Test Result for Case II

| Dependent Variable | IE | CF | IF | FF | HF | ER |
|---|---|---|---|---|---|---|
| IE | - | 0.362 | 0.720 | 0.533 | 0.174 | 1.583 |
| | - | 0.834 | 0.698 | 0.766 | 0.916 | 0.453 |
| CF | 10.730*** | - | 4.311 | 0.295 | 0.511 | 1.257 |
| | 0.005*** | - | 0.116 | 0.863 | 0.774 | 0.533 |
| IF | 5.535* | 10.976*** | - | 0.744 | 2.013 | 0.769 |
| | 0.063* | 0.004*** | - | 0.689 | 0.365 | 0.681 |
| FF | 6.286** | 6.173** | 3.846 | - | 1.073 | 0.246 |
| | 0.043** | 0.046** | 0.146 | - | 0.585 | 0.536 |
| HF | 5.442* | 1.960 | 10.619*** | 27.967*** | - | 1.718 |
| | 0.066* | 0.375 | 0.005*** | 0.000*** | - | 0.424 |
| ER | 8.807** | 0.333 | 1.030 | 0.136 | 0.213 | - |
| | 0.012** | 0.846 | 0.597 | 0.934 | 0.899 | - |

Note: see note in Table 1

Table 3. Modified Wald Test Result for Case III

| Dependent Variable | FE | CF | IF | FF | HF | ER |
|---|---|---|---|---|---|---|
| FE | - | 0.493 | 0.703 | 0.386 | 0.703 | 1.520 |
| | - | 0.782 | 0.704 | 0.824 | 0.704 | 0.468 |
| CF | 6.685** | - | 4.396 | 0.302 | 0.591 | 1.281 |
| | 0.035** | - | 0.111 | 0.860 | 0.744 | 0.527 |
| IF | 4.878* | 10.608*** | - | 0.805 | 2.364 | 1.019 |
| | 0.087* | 0.005*** | - | 0.669 | 0.307 | 0.601 |
| FF | 3.972 | 5.724* | 3.927 | - | 0.910 | 1.662 |
| | 0.137 | 0.057* | 0.140 | - | 0.635 | 0.436 |
| HF | 7.473** | 2.321 | 11.787*** | 28.485*** | - | 2.470 |
| | 0.024** | 0.313 | 0.003*** | 0.000*** | - | 0.291 |
| ER | 3.264 | 0.212 | 0.871 | 0.087 | 0.178 | - |
| | 0.196 | 0.899 | 0.647 | 0.958 | 0.915 | - |

Note: see note in Table 1

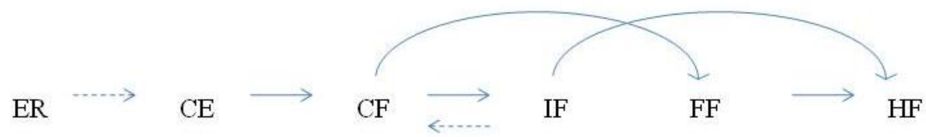


Figure 1. Price Transmission Mechanism for Case I

Note: see note in Table 1 and refer Table 1 for a specific significant level. Each (and dotted) arrow represents the identified causal flow at least 5% (and 10%) significant level in Granger sense.

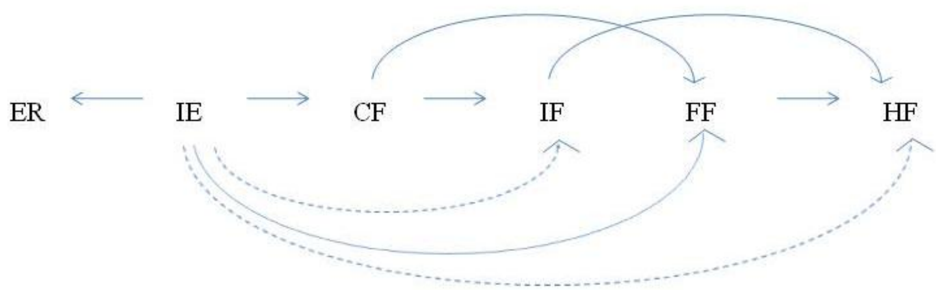


Figure 2. Price Transmission Mechanism for Case II

Note: see note in Figure 1 and refer Table 2 for a specific significant level.

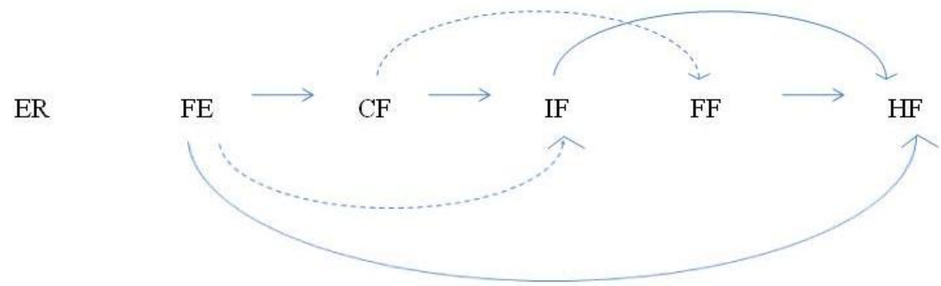


Figure 3. Price Transmission Mechanism for Case III

Note: see note in Figure 1 and refer Table 3 for a specific significant level.

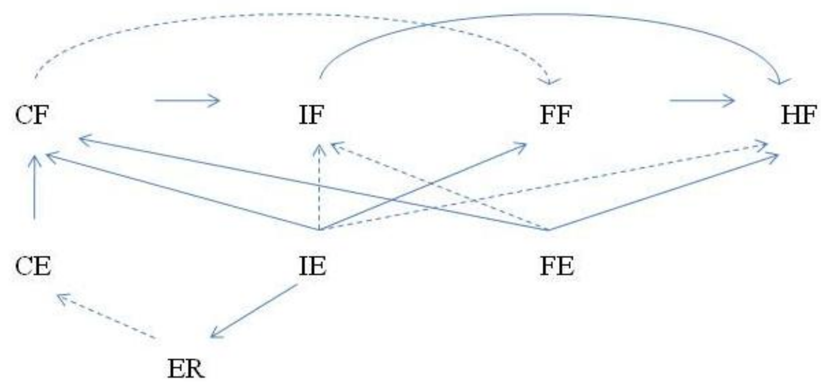


Figure 4. Price Transmission Mechanism

Note: see note in Figure 1 and refer Table 1-3 for a specific significant level.

[1] As research on sustainable agriculture has broadened into analyses of overall food systems, beyond farming, the heavy dependency of food system on energy consumption raises renewed

interests and there exist different estimates for the energy dependencies of the food system (Hendrickson 1996). For example, Hendrickson (1996) suggests that (i) the food system consumes close to 16% of the total energy use in the U.S., and (ii) agricultural production accounts for 18-28%, processing for 20-28% and household for 25-30%.

[2] According to several studies (e.g., Abbott, Hurt, and Tyner, 2008 and references in there) on the recent food inflation phenomenon, combined with the depreciation of the U.S. dollar, the rising energy prices put upward pressure on food prices through the expanded demand related to biofuel production and agricultural export and the increased production input costs mainly linked to fertilizer and pesticide prices.

[3] According to Hendrickson (1996), the use of inorganic fertilizers and pesticides increased dramatically between 1960 and 1980. For example, the fertilizer use expanded three times and herbicide use increased over four and half times in that period. Despite of the relatively declined usage since the early 1980s, they still represent the largest energy input into agriculture, raising concerns for the sustainable agriculture.

[4] Several studies (e.g., Lee and Scott 1999 and Weinhagen 2005) encompass the CPI for commodities as the additional stage of process, beyond the crude, intermediate, and finished stages of process in the PPI indexes.

[5] For the Formal definition of Granger Causality and complications related to its implications, we refer to Lütkepohl (1993). Note that there exist conceptual difference between philosophical notion based on manipulation and statistical concept based on predictability and thus we need to be cautions against over-interpreting the empirical results based on the Granger causality concept (e.g., Pearl 2000). Note also that there exist three approaches of formal tests of restrictions, innovation accounting of impulse response functions and forecast error variance decompositions

(e.g., Lütkepohl 1993), and incremental predictive performance comparison (e.g., Gelper and Croux 2007), we focus on the formal restriction test in this study.

[6] There are three approaches to implement GNC test, depending on time-series properties of variables: a VAR model in the level data (VARL), a VAR model in the first-differenced data (VARD), and a vector error correction model (VECM). However, the non-stationary properties such as unit roots and cointegration can result in statistical complications for testing GNC. Under some conditions, the VARL can involve a singular covariance matrix that may result in a non-standard asymptotic null distribution (e.g., Toda and Phillips, 1993) and the Least Square regression involving variables with unit roots may give rise to a spurious regression (e.g., Granger and Newbold 1974). When the series are cointegrated, the VARD may be misspecified as potential causality from the long-run relationship and thus some forecastability or Granger causality from one variable to the other is ignored (Engel and Granger 1987).

[7] For example, if we are interested in whether the $n_2$ elements are not causing the $n_1$ elements, the dimension of cointegrating space ( $\beta$ ) for the $n_2$ elements or the speed of adjustment space ( $\alpha$ ) for the $n_1$ elements must meet full rank conditions, which is not always satisfied under the null hypothesis. If such conditions are not satisfied, the limiting distributions under the null hypothesis need to be simulated in each relevant case and may depend on possibly unknown nuisance parameters, making it difficult or even impossible to use the appropriate statistical test.

[8] On the other hand, the VECM approach based on the sequential tests of cointegration exhibits serious size distortion, resulting severe over-rejection of non-casual null hypothesis. Although the Fully Modified VAR (FM-VAR, Phillips 1995) also does not require a pretest for a unit root and cointegration, thus can avoid pretest bias, the FM-VAR method does not always guarantee a desirable asymptotic size. Depending on the number and location of unit roots in the system, the

test can be quite conservative under the null hypothesis, which may cause loss of power under the alternative (Yamada and Toda 1998). Furthermore, Kauppi (2004) prove that FM-VAR estimator has second-order bias effects when some roots are local to unity. These bias effects are shown to result in potentially severe size distortions in FM-VAR testing when the hypothesis involves near unit root variables.