1. Introduction

The Food Price Monitoring Tool (FPMT) was developed in order to improve the accessibility of statistical data on prices in successive stages of a number of food supply chains. Today the tool reports on developments for agricultural commodity prices, producer prices, consumer prices and import prices.

A main goal of this project is to further enhance the Food Price Monitoring Tool. This will be accomplished by providing statistics and indicators for the assessment of the price transmission mechanism in the selected Food Monitoring Tool.

These statistics\(^1\) and indicators will provide information regarding:

- the magnitude (degree) of price transmission, i.e. how much of the price stage of the food supply chain will be transmitted to the next stage change in one
- the speed of price transmission, i.e. the pace at which price changes in one stage of the food supply are transmitted to the next stage
- the asymmetry of price transmission, i.e. to what extent price increases and decreases from one stage of the chain to the next are transmitted differently in terms of magnitude and speed

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\(^1\) In a few cases the estimated value of the size of price transmission, the asymmetry of price transmission and of other cost component effects is higher than 100% or negative (lower than 0%). Since those outliers are likely to be caused by spurious correlation or a very low number of observations, those values have been trimmed to 100% and 0% respectively.
2. General formulation of models

The analysis of the price transmission mechanism along the EU food supply chain has received considerable attention in recent years. The three main economic sectors of the food supply chain are the agricultural sector, the food processing industry and the distribution sector (wholesale, retail).

Understanding how food prices are adjusted along these sectors in terms of the magnitude of price changes, speed of price changes and asymmetric or symmetric price adjustment is important in order to specify characteristics of each sector as well as the functioning of the food supply chain in terms of effectiveness, efficiency, etc.

Various economic models have been studied in order to analyze price transmission of food prices in the food supply chain. These are mainly based on the use of Autoregressive distributed lag models. These models have been extended to Autoregressive distributed lag model with error correction term in order to account for possible cointegration between commodity prices. Relative studies that took place with the use of the above models in order to analyse price transmission in various food sectors are Buvevičiute, L., Dierx, A. and Ilzkovitz, F. (2009), Conforti, P. (2004), Chirwa E.W. (2001), Reziti, I., Panagopoulos, Y. (2008), Moghaddasi R. (2008).

Additionally, in the paper of the European Commission (2009), “Analysis of price transmission along the food supply chain in the EU” and in Varela, G., Tanigushi, K., (2014) similar models are applied with the addition of exogeneous variables (i.e. Labour Cost, Imports, e.t.c).


The models that have been applied in this study in order to analyze the price transmission along the food supply sectors are based on the aforementioned literature. The structure of these models is an Autoregressive distributed lagged model with exogenous variables and an error correction term (in cases it is econometrically appropriate to be incorporated into the estimated model).
2.1 Model 1: Price transmission along the food supply chain

The models presented below aim at obtaining indicators for the assessment of the magnitude and the speed of price transmission within the food supply chain.

- Transmission from agricultural commodity prices to producer prices

\[
\Delta PPI_t = c + \sum_{i=1}^{k} \alpha_i \Delta PPI_{t-i} + \sum_{i=0}^{k} \beta_i \Delta ACP_{t-i} + \sum_{i=0}^{k} \gamma_i \Delta Energy_{t-i} + \sum_{i=0}^{k} \varepsilon_i \Delta Importp_{t-i} + \varphi(PPI_{t-1} - bACP_{t-1}) + \mu_t
\]

**Model 1.1**

where, \( \Delta PPI_{t-i} \) are the autoregressive terms of the dependent variable, \( \Delta ACP_{t-i} \) are the agricultural commodity price variations, \( \Delta Energy_{t-i}, \Delta Importp_{t-i} \), are the exogenous variables of the model and \( (PPI_{t-1} - bACP_{t-1}) \), is the error correction term (or cointegrating vector) describing the long run effect of the agriculture commodity price levels to the producer price levels, with \( \varphi \) representing the adjustment coefficient to the long run equilibrium (in the case of cointegration among the data series).

- Transmission from producer prices to consumer prices

\[
\Delta HICP_t = c + \sum_{i=1}^{k} \alpha_i \Delta HICP_{t-i} + \sum_{i=0}^{k} \beta_i \Delta PPI_{t-i} + \sum_{i=0}^{k} \gamma_i \Delta Energy_{t-i} + \sum_{i=0}^{k} \varepsilon_i \Delta Importp_{t-i} + \varphi(HICP_{t-1} - bPPI_{t-1}) + \mu_t
\]

**Model 1.2**

where \( \Delta HICP_{t-i} \), are the autoregressive terms of the dependent variable, \( \Delta PPI_{t-i} \) are the producer price variations, \( \Delta Energy_{t-i}, \Delta Importp_{t-i} \), are the exogenous variables of the model and \( (HICP_{t-1} - bPPI_{t-1}) \), is the error correction term (or co-integrating vector) describing the long run effect of the producer price levels to the retailer price levels, with \( \varphi \) representing the adjustment coefficient to the long run equilibrium (in the case of co-integration among the data series).

- Transmission from agricultural commodity prices to consumer prices

\[
\Delta HICP_t = c + \sum_{i=1}^{k} \alpha_i \Delta HICP_{t-i} + \sum_{i=0}^{k} \beta_i \Delta ACP_{t-i} + \sum_{i=0}^{k} \gamma_i \Delta Energy_{t-i}
\]
Model 1.3

where $\Delta HICP_{t-i}$, are the autoregressive terms of the dependent variable, $\Delta ACP_{t-i}$ are the agricultural commodity price variations, $\Delta Energy_{t-i}, \Delta Import_{t-i}$, are the exogenous variables of the model and $(HICP_{t-1} - bACP_{t-1})$, is the error correction term (or co-integrating vector) describing the long run effect of the agriculture commodity price levels to the retailer price levels, with $\phi$ representing the adjustment coefficient to the long run equilibrium (in the case of co-integration among the data series).

2.2 Model 2: Asymmetry in price transmission along the food supply chain

- Transmission from agricultural commodity prices to producer prices

$$
\Delta PPI_t = c + \sum_{i=0}^{k} S^+_i a^+_i \Delta ACP_{t-i} + \sum_{i=0}^{k} S^-_i a^-_i \Delta ACP_{t-i} + \sum_{i=0}^{k} \beta_i \Delta PPI_{t-i} \\
+ \sum_{i=0}^{k} y_i \Delta Energy_{t-i} + \sum_{i=0}^{k} \varepsilon_i \Delta Import_{t-i} + \varphi (PPI_{t-1} - bACP_{t-1}) + \mu_t
$$

Model 2.1

where, $\Delta PPI_{t-i}$ are the autoregressive terms of the dependent variable, $\Delta ACP_{t-i}$ are the agricultural commodity price variations, $\Delta Energy_{t-i}, \Delta Import_{t-i}$, are the exogenous variables of the model, $(PPI_{t-1} - bACP_{t-1})$ is the error correction term (or co-integrating vector) describing the long run effect of the agriculture commodity price levels to the producer price levels, with $\phi$ representing the adjustment coefficient to the long run equilibrium (in the case of co-integration among the data series) and $S^+_i$ and $S^-_i$ are dummy variables which allow to study separately the effect of positive and negative variations of prices to the independent variable.

$$
S^+_i = \begin{cases} 
1 & \text{if } \Delta ACP_{t-1} \geq 0 \\
0 & \text{if } \Delta ACP_{t-1} < 0 
\end{cases} \\
S^-_i = \begin{cases} 
1 & \text{if } \Delta ACP_{t-1} \leq 0 \\
0 & \text{if } \Delta ACP_{t-1} > 0 
\end{cases}
$$

- Transmission from producer prices to consumer prices

$$
\Delta HICP_t = c + \sum_{i=0}^{k} S^+ a^+_i \Delta PPI_{t-i} + \sum_{i=0}^{k} DS^- a^-_i \Delta PPI_{t-i} + \sum_{i=0}^{k} \beta_i \Delta HICP_{t-i}
$$
where, $\Delta HICP_{t-1}$ are the autoregressive terms of the dependent variable, $PPI_{t-1}$ are the producer price variations, $\Delta Energyyp_{t-1}, \Delta Importp_{t-1}$, are the exogenous variables of the model, $(HICP_{t-1} - bPPI_{t-1})$ is the error correction term (or co-integrating vector) describing the long run effect of the producer price levels to the consumer price levels, with $\phi$ representing the adjustment coefficient to the long run equilibrium (in the case of co-integration among the data series) and $S^+_t$ and $S^-_t$ are dummy variables which allow to study separately the effect of positive and negative variations of prices to the independent variable.

$$S^+_t = \begin{cases} 1 & \text{if } \Delta ACP_{t-1} \geq 0 \\ 0 & \text{if } \Delta ACP_{t-1} < 0 \end{cases} \quad S^-_t = \begin{cases} 1 & \text{if } \Delta ACP_{t-1} \leq 0 \\ 0 & \text{if } \Delta ACP_{t-1} > 0 \end{cases}$$

### Transmission from agricultural commodity prices to consumer prices

$$\Delta HICP_t = c + \sum_{i=0}^{k} S^+_i a^+_i \Delta ACP_{t-i} + \sum_{i=0}^{k} S^-_i a^-_i \Delta ACP_{t-i} + \sum_{i=0}^{k} \beta_i \Delta HICP_{t-i}$$

$$+ \sum_{i=0}^{k} \gamma_i \Delta Energyyp_{t-i} + \sum_{i=0}^{k} \epsilon_i \Delta Importp_{t-i} + \varphi (HICP_{t-1} - bACP_{t-1}) + \mu_t$$

### Model 2.3

where, $\Delta HICP_{t-1}$ are the autoregressive terms of the dependent variable, $\Delta ACP_{t-1}$ are the agricultural commodity price variations, $\Delta Energyyp_{t-1}, \Delta Importp_{t-1}$, are the exogenous variables of the model, $(HICP_{t-1} - bACP_{t-1})$ is the error correction term (or co-integrating vector) describing the long run effect of the agriculture commodity price levels to the consumer price levels, with $\phi$ representing the adjustment coefficient to the long run equilibrium (in the case of co-integration among the data series) and $S^+_t$ and $S^-_t$ are dummy variables which allow to study separately the effect of positive and negative variations of prices to the independent variable.

$$S^+_t = \begin{cases} 1 & \text{if } \Delta ACP_{t-1} \geq 0 \\ 0 & \text{if } \Delta ACP_{t-1} < 0 \end{cases} \quad S^-_t = \begin{cases} 1 & \text{if } \Delta ACP_{t-1} \leq 0 \\ 0 & \text{if } \Delta ACP_{t-1} > 0 \end{cases}$$
3. Statistical Tests and Model Diagnostics

Tests on the variables of the regression

1. Multicollinearity of explanatory variables

Multicollinearity (also collinearity) is a statistical phenomenon in which two or more explanatory variables in a multiple regression model are highly correlated. The existence of multicollinearity may lead to unstable parameter estimates.

Multicollinearity is tested via the Variance Inflation Factor (VIF). The VIF is a measure of how much the variance of each estimated coefficient is inflated. A high VIF indicates multicollinearity among some of the explanatory variables.

2. Outlier detection

The results of any statistical analysis are just as reliable as the quality of the data. Thus it is important to detect and handle outliers in the data. In this particular analysis, Eurostat’s official software, namely JDemetra+, is facilitated for the detection of outliers in the dependent series of the regression and simultaneous adjustment in order to account for these. The types of outliers considered are additive outliers (AO) and level shifts (LS).

3. Cointegration/Unit roots

A common issue that arises in the price transmission among the stages of the supply chain is the existence of co-integration between the commodity variables. The test for co-integration between commodity variables determines the presence or not of a long run relationship between the underlined variables. In the case co-integration is present then a long run price relationship can be established.

Co-integration between 2 variables exists when they are non-stationary and there exists a linear combination of their integrated values that is stationary. If 2 non-stationary series are co-integrated then the extent to which they diverge from each other will have stationary characteristics and will reflect only the disequilibrium. Thus, co-integration allows us to capture the equilibrium relationship between series that are non-stationary. Co-integration implies that prices move closely together in the long run, although in the short run they may drift apart.

The existence of co-integration is tested based on the following approach.

Step 1: Test whether each series is non-stationary. This is equivalent to the existence of unit-roots. The most common case is for a series to have one unit root, than to be non-stationary.
**Step 2:** Run a regression model against the series tested in Step 1 and examine whether a significant relationship between the 2 series exists.

**Step 3:** Test the stationarity of the residual series of the regression model. If the series is stationary then the two series are said to be cointegrated. In such a case an error correction term is introduced in the price transmission models (see Grasso and Manera (2007), Frey and Manera (2007)).

The following graph analytically presents the process for the determination of co-integration for the price transmission from agricultural commodity prices to producer prices.

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4. **Causality test**

Causality is the phenomenon in which one time series is useful in predicting another time series; there exists a cause-effect relationship between the two variables.

The Granger Causality test is very popular in econometrics. Testing causality, in the Granger sense, involves using F-tests to test whether lagged information on a variable Y provides any statistically significant information about a variable X in the presence of lagged X. If not, then "Y does not Granger-cause X."

In the analysis of price transmission along the food supply chains the Granger Causality test may assist in examining whether there is a causal relationship between agricultural commodity prices, producer prices and consumer prices.
Tests on the residuals of the regression

1. Tests for Heteroscedasticity

A main assumption for regression analysis is the homogeneity of variance of the residuals. If the model is well fitted then no pattern exists between the residuals and the fitted values. The existence of heteroscedasticity is a major concern in regression analysis since it produces inefficient estimators and standard errors thus influencing statistical significance tests.

In order to check for heteroscedasticity the following tests may be applied:

- Plots of residuals against predicted or explanatory values or scatterplot of residuals: If the variation of the residuals presents a ‘pattern’ then heteroscedasticity may exist.
- Statistical tests, such as the White test: The White test examines the null hypothesis that the variance of the residuals is homogenous. In cases where the White test statistic is statistically significant, heteroscedasticity may not necessarily be the cause, but issues regarding an adequate model specification. For this reason the applied test is always accompanied with the previous referred plots (see White H., 1980).

2. Test for Autocorrelation

In order to check whether the residuals of the model are independent or correlated (presence of autocorrelation) the following tests are applied:

- *Plots of residuals against predicted or explanatory values or against the residuals lag 1 values.* If a pattern is observed then this may be an indication of autocorrelation.
- *Statistical tests, such as the Durbin-Watson test.* If the Durbin-Watson statistic values tend to 0 then this is an indication of positive autocorrelation. If the Durbin-Watson statistic value tends to 4 then this is an indication of negative correlation autocorrelation. Values around 2 indicate no-autocorrelation.
- In cases where the lagged dependent variables are included in the explanatory variables then Durbin Watson test is not applicable since it tends to
underestimate. In these cases, other statistical test such as Durbin h or t test may be applied.

**Asymmetry tests**

Asymmetry of price transmission is tested based on a two step approach:

1) **F-test of linear constraints on specific coefficients of the asymmetry model**

This involves testing a hypothesis concerning a subset of the variables in the estimated asymmetry model. Two models are compared:

- the asymmetry model: it is the model including segmented variables describing price increases and price decreases (known as “Houck approach” Houck (1977), see also section 2.2. and models 2.1, 2.2, 2.3). This is the “unconstrained model”.
- “Constrained model”: this assumes strong evidence of symmetry in price transmission. This model is the one arising under the Ho hypothesis of this test.

The general format of the F-test is the following:

\[ H_0: \beta_i^+ = \beta_i^-, i = 1, \ldots, k \]
\[ H_1: \beta_i^+ \neq \beta_i^-, \text{for at least one } i = 1, \ldots, k \]

Thus,

- estimate the asymmetry model – unconstrained model
- estimate the model based on Ho which implies symmetric price transmission
- compute the incremental F-statistic comparing the two models:

\[ F = \frac{(SSE_u - SSE_0)/j}{SSE_u/df_u} \]

where, \( j \) = # of constraints of Ho and \( df_u \) the degrees of freedom of the unconstrained model.

Two cases of asymmetric price transmission can be tested:

- **Asymmetry in speed**: this implies that \( \beta_i^+ \neq \beta_i^- \) applies for at least one pair.
- **Asymmetry in magnitude**: \( \sum \beta_i^+ \neq \sum \beta_i^- \) for all values of i.

The F-test can be used for evaluating at least asymmetry in speed. Cases that also reveal asymmetry in magnitude are those for which \( H_0 \) is verified for all values of i.

2) **Additional evaluation of asymmetry coefficients values and significance and the difference of totals of increases and decreases coefficients are evaluated.**

Example: in cases of only two coefficients in the asymmetry model (\( \beta_1^+, \beta_1^- \)) of which only one is insignificant (\( \beta_1^+ \) or \( \beta_1^- \)) or in cases of four coefficients (\( \beta_1^+, \beta_1^-, \beta_2^+, \beta_2^- \)) of which both increases coefficients (\( \beta_1^+, \beta_2^+ \)) or decreases coefficients (\( \beta_1^-, \beta_2^- \)) are insignificant the F-test is not applied and asymmetric price transmission is assumed.
Asymmetry in magnitude can also be supported by the observed differences of estimated cumulative asymmetry coefficients and their significance levels.
4. **Price Transmission Analysis along the Food Supply Chain**

The application of the econometric models described in chapter 2 aims in capturing the explanatory characteristics of the price transmission process. The main estimates that are produced refer to the price transmission coefficients that link each two stages of the food supply chain e.g. agricultural commodity prices and producer commodity prices. Such coefficients provide an approximation of the **magnitude of price transmission** and the **speed of price transmission**. However the levels of magnitude and speed may vary in the case of price increases and in the case of price decreases causing **asymmetrical effects**.

The magnitude and the speed of price transmission may not be fully captured by the input commodity variables (e.g. agricultural commodity prices, producer commodity prices). Thus, several characteristics of the markets where each food products’ prices are formed may affect the process.

Moreover, the presence of a long-run relationship among the commodity prices may exist. Assuming a long-run relationship exists, this will be incorporated into the models with the inclusion of an error correction term.

Finally other characteristics refer to the cost structure of a production and/or distribution process (see. European commission 2009) which implies the effect (current and/or in the form of distributed time lags) of costs such as labour costs, energy costs and import costs.