Analysing production shocks in global wheat markets using GVAR models

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Abstract

This study analyses the global wheat market with a relatively new modelling strategy in agricultural market studies: the global vector autoregression (GVAR) model. This methodology provides a solution to the high dimensional structure of complex systems by weighting average foreign variables, and allows for analysing market developments on both a short-run and long-run basis. The objective of this study is to analyse the advantages and disadvantages of using a GVAR modelling approach for the global wheat market. To this extent, existing literature is analysed and the key characteristics of the model are explored. Next, a small model of the global wheat market is developed including five major exporting countries and monthly data on their wheat export prices, their nominal exchange rate and the oil price. The country-specific weights are constructed using export shares, which are then used to develop country-specific foreign wheat price variables. After estimating the country-specific equations, the global model is solved. To test the reliability of the weights, the model is also estimated as an unrestricted VECM with the same model structure. Although the GVAR modelling approach was found to be suitable to model the global wheat market, some disadvantages were found that call for further research.

Keywords: GVAR models, commodity markets, wheat

JEL code: C32, Q02, Q13

1. Introduction

Many agricultural commodities are traded globally and are therefore subject to international economic interdependences. There has been increasing attention for these linkages among agricultural commodities after the 2007-2008 world food crisis in which food price volatility and price levels rapidly increased. Attention of academics and policy makers was drawn to the causes of this food crisis. Extreme weather events, low stocks, high oil prices, increasing demand for biofuels, speculation and trade shocks have been widely discussed as possible causes (Headey, 2011). One of the most traded agricultural commodities in the world is wheat, from which 20 percent of the total production is traded internationally (FAOSTAT, 2014). While many countries import wheat for human consumption and for the use of compound feed in the livestock sector, there are only a few big exporters on the market (e.g. USA, EU, Australia and Canada). Strong interdependencies also influence the global wheat market. Macroeconomic variables influence e.g. the demand for wheat, so when these variables co-move between countries, shocks in one country's macroeconomic variables can have an effect on domestic wheat markets in other countries. But besides the co-movement of macroeconomic variables, there are more interdependencies among countries on the global wheat market due to high amount of trade that is taking place. Therefore, shocks in one country affect other countries directly since trade flows adjust. For example, the strong wheat import dependency of many developing countries makes that policy changes or environmental shocks in producing countries have a direct effect on the availability and price development in the importing countries. But also common factors play an important role, such as the oil price, influencing both the global wheat market on the demand side (for the use of biofuel) and supply side (as agricultural input). So, due to its multilateral nature and the more pronounced international interdependencies, the international wheat market calls to be analysed from a global perspective such that the integration of economies and the spill-over effects across nations can be considered.

In analysing global commodity markets two different types of models are commonly used: Computable General Equilibrium (CGE) models and time-series econometric models. CGE models are simulation models based on economic theory where parameters are calibrated and most often yearly data is used. Time-series econometric models, on the other hand, are based on time-series observations, parameters are estimated and higher frequency data (monthly, weekly, daily) can be used. Whereas CGE models are often considered as complex with results that are difficult to interpret (Piermartini et al., 2005), econometric commodity market models are often criticized for their weak theoretical basis. Moreover, econometric commodity market models based on VAR or VECM specifications are often limited in the number of variables they can accommodate.

This paper presents a Global Vector Auto-Regression (GVAR) model for the global wheat market. A GVAR model is a macro-econometric model that relies on time-series observations, which is often estimated subject to long-run relationships obtained from economic theory. Due to this structure, the long-run relationships are consistent with economic theory while the short run relationships are still consistent with the time-series observations (di Mauro and Smith, 2013). Besides the fact that the model is taking economic theory into account, another advantage of the GVAR modelling approach is that it allows for international linkages among a large number of countries. The GVAR approach was developed by Pesaran et al. (2004a) and thus far mainly has been applied for macro-economic and financial market analyses. Exceptions are Bussière et al. (2009) who modelled international trade and global imbalances and Gutierrez and Piras (2015) who analysed wheat export prices using a GVAR modelling approach. Our paper differs from Gutierrez and Piras (2014) in that we use a slightly different model setup, different data and different weights in constructing the foreign variables.

The next section discusses the GVAR global wheat model structure, follows by a discussion of the data and weights used. Section 4 presents the results for the individual country models and the solved GVAR is discussed in section 5. Impulse Response analyses are presented in section 6 and the final section provides conclusions and discussion on the approach used.

2. A GVAR model for the global wheat market

A GVAR model is constructed in two main steps; in the first step country-specific VAR models are estimated and tested, and in the second step all the estimated coefficients are stacked together and solved in one system, the GVAR. The country-specific models include domestic variables and common foreign variables, which link the country-specific models to each other and makes co-integration possible between domestic variables of a country but also between the domestic and foreign variables. In these specific-country models long-run co-integrating relationships can be tested and imposed. The foreign variables are a weighted average of the countries included in the sample and are assumed (and tested) to be weakly exogenous. Assuming the foreign variables to be weakly exogenous, as di Mauro and Smith (2013) discuss, is a key characteristic of the model. In this way the number of equations to be estimated is significantly reduced and therefore it bypasses the curse of dimensionality which is a common problem in global macroeconomic modeling using unrestricted VAR models (Chudik and Smith, 2013). From the solution of the GVAR impulse response functions can be derived, which investigate the effects of a shock in one of the variables on the other variables in the model (Pesaran and Smith, 2006). For a detailed discussion on GVAR modelling see Pesaran et al. (2004a), di Mauro and Pesaran (2013) or Chudik and Pesaran (2016).

As discussed in the introduction, many studies analysed the causes of agricultural commodity price spikes. The explanations of the food crisis are factors mostly influencing the supply side of the wheat market, rather than the demand side, e.g. extreme weather events, the depreciation of the US dollar, low stocks, high oil price and demand for biofuel. Demand of wheat is to a great extent explained by income and population growth, which are rather stable. For this reason our model only includes major wheat exporting countries, i.e. Argentina, Australia, Canada, the EU and the US. These countries are spread across the globe and account together for almost 80% of all wheat exports between 2007 and 2011 (FAOSTAT, 2014).

The model includes the following variables: wheat export prices, exchange rates and the price of oil. Exchange rates determine how international prices are translated into domestic prices and have been suggested to be a major factor in the explaining commodity prices (Mitchell, 2008). A second variable that is included in the model is the crude oil price. The international oil price and prices of agricultural commodities are linked to each other on the input side through different channels. First of all, the energy that is used in agricultural production is mainly oil-based (such as the farm vehicles and machinery that are mostly powered by fossil fuels). Furthermore, the prices of fertilizer and other chemicals used in the production process are related to energy prices (Mitchell, 2008). Heady and Fan (2008) show that the oil price increase has a big impact on the production costs through these two channels. They estimate that due to the increased oil price the costs of US production of corn, wheat and soybeans increased by 30-40% over 2001-2007 relative to a situation in which the oil-related prices only increased by inflation. At last, a higher oil price also increases the cost for transportation. Additionally, higher oil prices induce higher demand for biofuels (de Gorter, 2008). Although wheat is not a major feedstock for biofuel production, higher biofuel demand can lead to lower supply of wheat since farmers will substitute wheat for a crop that is demanded for biofuel production. By including the exchange rate and the price of oil into the model, we are able to analyse the effects of a shock in one of these variables and its way of transmission among the different countries. The final variable and the most important one is the wheat price, which will serve the main goal of the model: to analyse the interdependencies in the price movements across the countries. It is chosen not to include specific supply and demand variables due to data limitations. Nevertheless, the model is still suitable to analyse the effect of supply shocks even though supply side variables are not directly taken into account. For instance, production shortfalls due to extreme weather events can still be analysed by imposing a corresponding price increase in the specific country.

The primary variables of interest in this model are the domestic wheat prices $P_{i,t}$ and the country-specific foreign counterparts $P^*_{i,t}$. The country-specific foreign wheat prices, $P^*_{i,t}$, ensure that shocks in the domestic price of country i are channeled through to the domestic prices of all other countries and the other way around. The degree to which these shocks are channelled through depends on the weights used to construct the domestic variables out of the country-specific foreign prices. The foreign wheat prices are constructed as follows:

$$P^*_{i,t} = \sum_{j=0}^{N} w_{ij} P_{j,t}. \tag{1}$$

where w_{ii} equals zero and the sum of w_{ij} is always equal to 1 for any country i. So, $P_{i,t}$ is not included in its own weighted average foreign variable $P^*_{i,t}$. This method is desirable since the model only includes 5 countries and therefore the share of $P_{i,t}$ in $P^*_{i,t}$ could be significantly large, endangering the weakly exogenous assumption of $P^*_{i,t}$.

In the existing literature on GVAR modelling such as Dees et al. (2007b), the oil price is often treated as endogenous in the country-specific model for the US, assuming that due to the large size of the US economy US macroeconomic variables will influence the oil price. Our model deviates from existing GVAR models, since it does not include a wide range of macroeconomic factors but focuses solely on wheat price developments. Therefore we assume the oil price to be exogenous for wheat prices and include the oil price as exogenous variable in all country-specific models. The same assumption is made for the exchange rate.

These assumptions reduce the global VAR model to a model where each country only has one endogenous variable, the price of wheat. Hereby, each country-specific model is reduced to the following autoregressive distributed lag (ADL) model

$$P_{i,t} = \beta_{i1} + \beta_{i2} t + \sum_{k=1}^{p_i} \alpha_{ik} P_{i,t-k} + \sum_{l=0}^{q_i} \gamma_{il} P^*_{i,t-l} + \sum_{l=0}^{q_i} \delta_{il} ER_{i,t-l} + \sum_{l=0}^{q_i} \theta_{iL} PO_{t-l} + \varepsilon_{i,t} \tag{2}$$

where $P_{i,t}$ is the price of wheat, $P^*_{i,t}$ the country-specific foreign price of wheat, which is a weighted average of the other countries' wheat prices, $ER_{i,t}$ the exchange rate and PO_t the oil price. The lag orders are given by p_i and q_i, where p_i is the number of lags used for the domestic variable and q_i the number of lags used for the (weakly) exogenous variables. By imposing the same lag order for the (weakly) exogenous variables the model is given a certain structure. However, the values for p_i and q_i can still differ from each other and between the different countries.

3. Data and construction of weights

For all variables, monthly data is used covering the period from July 2001 until April 2012. Table 1 shows the definition of the variables and the source that is used to collect the data.

Table 1. Definition and data source of the included variables

Variable	Definition	Source
$P_{i,t}$	Wheat export price in US dollars per ton	International Grains Council (2012)
PO_t	Average of nominal Brent, Dubai and West Texas Intermediate crude oil prices in US dollars per barrel	World Bank Commodity Price Data (Pink Sheet) (2014)
$ER_{i,t}$	National currency per SDR, end of period	International Financial Statistics (2014)

The wheat prices for the five countries included are shown in figure 1:

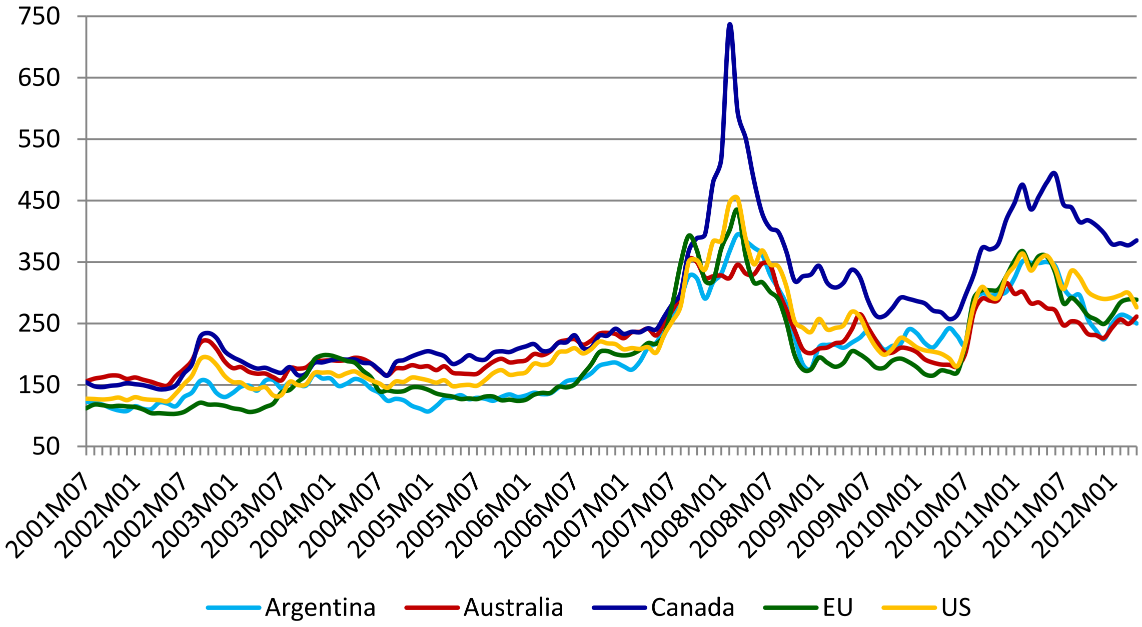

Figure 1. Monthly wheat prices for major exporters (USD/tonne)

Source: International Grains Council (2012). Missing observations constructed by author.

While the data for the oil price and the exchange rates where fully available for all countries and months, the wheat price data contained missing observations. In most of the cases it concerned only one or two missing observations at a time, which could be solved by interpolation. However, wheat prices for Australia were missing for the period October 2007 until November 2008. Values were imputed using a combination of forecasting and backcasting, based on a time-series models relating Australian wheat prices and barley prices, which were available for the full period.

The country-specific weights are used in constructing the country-specific foreign variables from the domestic variables and represent the degree to which one country depends on the other countries in the sample. We base the weights on trade shares, assuming that the countries are linked through arbitrage. Because the model only includes exporters, the weights are not based on trade flows between one and another, since trade between these exporters will be small or negligible. Rather, the relative importance will be determined by the share that the country is holding in total exports. For example, a supply shock in a country that is a big exporter will influence country i more than a supply shock in a small exporter. Therefore the weights are constructed as the average ratio over 2009-2011 of a country's exports volume to total exports of all the other countries included in the model, such that

$$w_{ij} = \frac{EX_j}{(\sum_{i=0}^{N} EX_i) - EX_i} \quad (3)$$

where EX_i is the wheat export volume of country i in the period 2009-2011, which were obtained from FAOSTAT (2014). Table 2 shows the constructed weights.

Table 2. Country-specific weights based on wheat export share

Variables	Argentina	Australia	Canada	EU	USA
Argentina	0.000	0.198	0.220	0.246	0.336
Australia	0.082	0.000	0.252	0.281	0.384
Canada	0.084	0.233	0.000	0.289	0.394
EU	0.087	0.240	0.267	0.000	0.407
USA	0.097	0.269	0.299	0.334	0.000

Source: Authors' calculations based on FAOSTAT (2014).
Note: The weights are displayed in row by country and therefore every row, not column, sums up to 1. In this table some rows do not exactly sum op to 1 due to fact that the numbers are rounded.

4. Results for country-specific models

4.1. Order of integration, lag order and cointegration

For all countries the time-series of the four different variables were tested for unit roots using the Augmented Dickey-Fuller test and the KPSS test using a 1% significance level. For two time-series the Dickey-Fuller test and the KPSS test gave contradictory results. For the other time-series both tests indicated the series to be integrated of order one. Therefore the analysis is continued using first-differenced data.

To determine the initial lag order a distinction was made between the number of lags used for the domestic variables, p_i, and the number of lags used for the (weakly) exogenous variables, q_i, such that the model is given a certain structure. Furthermore, we impose a maximum lag order of 3 for both p_i and q_i. The initial lag order is then determined by comparing AIC and BIC values of country-specific VAR models with all the possible different combinations of lag orders for p_i and q_i. The results of this analysis are shown in table 3.

Table 3. Number of lags $(\boldsymbol{p_i}, \boldsymbol{q_i})$

Country	AIC	BIC
Argentina	(3,3)	(3,0)
Australia	(1,3)	(3,0)
Canada	(2,3)	(3,0)
Europe	(1,3)	(3,0)
US	(3,0)	(3,0)

Except for the US, the AIC and BIC give different optimal lag order combinations. Shown in the results, the BIC penalizes the number of parameters stronger than the AIC does. We decide to continue with the optimal number of lags preferred by the BIC. From a theoretical point of view, including the lags of the domestic wheat price itself is expected to have more influence on the domestic wheat price at time t than the lags of the (weakly) exogenous variables. Besides that, the model structure will be more consistent following the BIC outcome. Therefore the analysis is continued with the following country-specific models

$$P_{i,t} = \beta_{i1} + \beta_{i2}t + \alpha_{i,1}P_{i,t-1} + \alpha_{i,2}P_{i,t-2} + \alpha_{i,3}P_{i,t-3} + \gamma_i P^*_{i,t} + \delta_i ER_{i,t} + \theta_i PO_t + \varepsilon_{i,t} \quad (4)$$

Since all series are integrated of order one it is possible that co-integrating relationships exist among them. In this analysis, the search for co-integrating relationships is aimed on the domestic price of wheat in relationship with the other variables, since the domestic price of wheat is the only endogenous variable included in the model. Table 4 shows the results of tests for cointegration. For every country one co-integrating relationship was found. As was expected, all the co-integrating relationships include the country-specific foreign wheat prices $P^*_{i,t}$. For the domestic wheat price of the US, not only the country-specific foreign wheat price is found to be long run forcing, so is the oil price. For the Canadian domestic wheat price the country-specific foreign wheat price, the oil price, as well as the Canadian exchange rate are proven to be long run forcing.

Table 4. Co-integrating relationships

Country	r	Co-integrating variables
Argentina	1	$P_{ar,t},\ P^*_{ar,t}$
Australia	1	$P_{au,t},\ P^*_{au,t}$
Canada	1	$P_{ca,t},\ P^*_{ca,t}, PO_t, ER_{ca,t}$
Europe	1	$P_{eu,t},\ P^*_{eu,t}$
US	1	$P_{us,t},\ P^*_{us,t}, PO_t$

4.2. Country-specific estimation results

Taking the order of integration, the chosen lag order and the co-integration relationship into account, the country-specific models were estimated in their error correction form. Table 5 shows the estimation results for both a full and a reduced specification. A deterministic trend was not significant in any of the country-specific models and is therefore left out from all the country-specific models. Only in the country-specific model for Australia the constant was found to be significant. The reduced model includes only the variables and their lags from which the coefficients are significantly different from zero at a 5% significance level. There are two exceptions were variables were included in the reduced model even though they were not significant in the full model. The first exception applies for the variables of the error correction term that were not significant (which are $ER_{ca,t-1}$ and PO_{t-1} for the Canadian equation and PO_{t-1} for the equation of the US). It was chosen to not exclude these variables since it was proven that these variables belong to the long-run relationship influencing $P_{ca,t}$ and $P_{us,t}$, respectively. Furthermore, the error-correction term as a whole was in both cases significant. The second exception applies for lagged variables that were not significant but higher lag orders of the same variables were significant. This was the case for $\Delta P_{ca,t-1}$ and $\Delta P_{us,t-1}$ in the equation of Canada and the US, respectively.

Table 5. Estimation results

Country	Variables	Parameters full model		**Parameters reduced model**	
Argentina	*Error correction term:*				
	Adjustment parameter	-0.170	(0.046)***	**-0.186**	**(0.044)*** **
	$P^*_{ar,t-1}$	0.893	(0.023)***	**0.890**	**(0.021)*** **
	$\Delta P_{ar,t-1}$	0.258	(0.066)***	**0.265**	**(0.059)*** **
	$\Delta P_{ar,t-2}$	-0.106	(0.069)	-	-
	$\Delta P_{ar,t-3}$	0.029	(0.066)	-	-
	$\Delta P^*_{ar,t}$	0.579	(0.055)***	**0.593**	**(0.055)*** **
	$\Delta ER_{ar,t}$	-8.082	(5.121)	-	-
	ΔPO_t	0.392	(0.194)**	-	-
Australia	*Constant*	22.776	(5.604)***	**18.834**	**(4.788)*** **
	Error correction term:				
	Adjustment parameter	-0.216	(0.053)***	**-0.180**	**(0.045)*** **
	$P^*_{au,t-1}$	0.500	(0.049)***	**0.501**	**(0.058)*** **
	$\Delta P_{au,t-1}$	0.257	(0.686)***	**0.237**	**(0.065)*** **
	$\Delta P_{au,t-2}$	-0.015	(0.073)	-	-
	$\Delta P_{au,t-3}$	0.101	(0.071)	-	-
	$\Delta P^*_{au,t}$	0.468	(0.049)***	**0.450**	**(0.048)*** **
	$\Delta ER_{au,t}$	24.253	(17.523)	-	-
	ΔPO_t	0.573	(0.185)***	**0.530**	**(0.160)*** **
Canada	*Error correction term:*				
	Adjustment parameter	-0.225	(0.060)***	**-0.225**	**(0.059)*** **
	$P^*_{ca,t-1}$	1.744	(0.342)***	**1.730**	**(0.321)*** **
	$ER_{ca,t-1}$	-32.498	(17.070)*	**-32.125**	**(16.284)* **
	PO_{t-1}	-0.582	(0.828)	**-0.547**	**(0.782)**
	$\Delta P_{ca,t-1}$	-0.127	(0.081)	**-0.128**	**(0.080)**
	$\Delta P_{ca,t-2}$	0.170	(0.075)**	**0.171**	**(0.073)** **
	$\Delta P_{ca,t-3}$	-0.010	(0.075)	-	-
	$\Delta P^*_{ca,t}$	1.139	(0.148)***	**1.142**	**(0.145)*** **
	$\Delta ER_{ca,t}$	-99.754	(49.220)**	**-99.203**	**(48.680)** **
	ΔPO_t	-0.962	(0.413)**	**-0.970**	**(0.399)** **
Europe	*Error correction term:*				
	Adjustment parameter	-0.120	(0.049)**	**-0.146**	**(0.043)*** **
	$P^*_{eu,t-1}$	0.855	(0.040)***	**0.855**	**(0.032)*** **
	$\Delta P_{eu,t-1}$	0.268	(0.081)***	**0.227**	**(0.067)*** **
	$\Delta P_{eu,t-2}$	-0.105	(0.082)	-	-
	$\Delta P_{eu,t-3}$	-0.011	(0.075)	-	-
	$\Delta P^*_{eu,t}$	0.707	(0.079)***	**0.752**	**(0.073)*** **
	$\Delta ER_{eu,t}$	-47.557	(55.593)	-	-

	$\Delta\, PO_t$	0.094	(0.228)	-	-
US	*Error correction term:*				
	Adjustment parameter	-0.274	(0.069)***	**-0.297**	**(0.066)*** **
	$P^*_{us,t-1}$	0.942	(0.053)***	**0.967**	**(0.047)*** **
	PO_{t-1}	0.115	(0.184)	**0.033**	**(0.164)**
	$\Delta\, P_{us,t-1}$	-0.016	(0.043)	**-0.024**	**(0.042)**
	$\Delta\, P_{us,t-2}$	-0.125	(0.041)***	**-0.113**	**(0.040)*** **
	$\Delta\, P_{us,t-3}$	0.075	(0.042)*	-	-
	$\Delta\, P^*_{us,t}$	0.977	(0.047)***	**0.978**	**(0.046)*** **
	$\Delta\, ER_{us,t}$	36.398	(34.747)	-	-
	$\Delta\, PO_t$	-0.050	(0.145)	-	-

Note: Standard errors between parentheses. * Significant at a 10% significance level, ** Significant at a 5% significance level, *** significant at a 1% level.

The exchange rate was only found to be significant in the country-specific equation for Canada. The dollar depreciation is often given as an explanation for the higher (agricultural) prices in recent years. Nonetheless, in this model there is no evidence found that the exchange rate plays a significant role in explaining domestic wheat prices, except for Canada. Also the price of oil is not significant in every country-specific equation. For Argentina and Europe the price of oil does not play a significant role in determining their domestic wheat price. For Australia, the price of oil is only found to be significant in short-term relation. Whereas for Canada and the US, the price of oil is found to be significant both in short term as well as in the long term relation.

The number of lags of the different variables included in equations (28)-(32) are different from the lag orders specified according to the BIC in paragraph 5.1. The BIC is a good starting point to determine the optimal lag order since the model complexity allows for many different combinations of the number of lags. However, after including the co-integrating relationships, the optimal lag order changes and the significance of parameters is taken into account. Garatt et al. (2006, p.108) emphasize the difficulty of determining the lag orders in global modelling exercises due to the many different combinations that can exist. In this relatively small model we were able to identify all the parameters that are not significant and remove the associate variables from all the country-specific equations. As one can imagine, this is harder to realize in a more complex model. In that case, one could prefer to hold on to the structure selected by the BIC. This is often done in the literature discussed earlier, where authors often stick to the AIC or BIC preferred lag orders while not taking into account the significance of their parameters.

The estimation of the country-specific equations, shown in table 5, makes it possible to analyse the co-movement between the domestic wheat price and its foreign counterpart in every country-specific equation. Table 6 shows the impact of an increase of 1 dollar in the country-specific foreign wheat price, $P^*_{i,t}$, on the domestic wheat price, ceteris paribus. The coefficients give insight in the international linkage between the domestic and the foreign wheat price. All five parameters are found to be significant and positive, indicating that in all countries the domestic price and the foreign price move in the same direction. Only in the case of Canada the parameter is bigger than 1, indicating that whenever the foreign price increases the effect on the domestic wheat price of Canada will be stronger. Looking at the data in figure 1, this was expected since the Canadian wheat price has been the highest of all domestic prices in most of the time period. Furthermore, table 6 shows that the domestic prices of the US and Europe are more affected by the foreign price than the domestic prices of Argentina and Australia.

Table 6. Effects of country-specific foreign wheat price on domestic wheat price

Country	$P^*_{i,t}$	
Argentina	0.593	(0.055)***
Australia	0.450	(0.048)***
Canada	1.142	(0.145)***
Europe	0.752	(0.073)***
US	0.978	(0.046)***

Note: between parentheses the standard errors. * Significant at a 10% significance level, ** Significant at a 5% significance level, *** significant at a 1% level.

4.3. Testing weak exogeneity

As explained before the assumption that the foreign country-specific variables $P^*_{i,t}$ are weakly exogenous can be tested. Assuming foreign country-specific wheat prices to be weakly exogenous means that all countries are assumed to be small economies with respect to the rest of the world. Since only a few big exporters dominate the global wheat market there is a possibility this assumption will not hold for every country in this analysis. Assuming that $P^*_{i,t}$ is weakly exogenous, deviations from the long-run equilibria in country i will not affect $P^*_{i,t}$. This implies that the parameter of the error correction term is not significantly different from zero in the regression of $P^*_{i,t}$ in first differences. This assumption was tested for all 5 countries, from which the results can be found in table 7.

Table 7 Weak exogeneity tests for $P_{i,t}^{*}$

Country	t-statistic
Argentina	0.17
Australia	0.78
Canada	-1.36
Europe	2.1**
US	-2.8 ***

Note: ** Significant at a 5% significance level, *** significant at a 1% level.

For Argentina, Australia and Canada the weakly exogeneity assumption of P_t^* holds at the 5% level, whereas for Europe it only holds a the 1% level. For the US it can be concluded that $P_{us,t}^*$ is not weakly exogenous with respect to $P_{us,t}$ and consequently that the small economy assumption of the US does not hold.

Because the weak exogeniety assumption does not hold for the US, various solutions were considered. First, an analysis was performed to see if any of the lags of P_{us}^* could serve as an instrumental variable. This was the case for the seventh lag, $P_{us,t-7}^*$. Therefore, the country-specific equation of the US is re-estimated using 2SLS and $P_{us,t-7}^*$ as instrumental variable for $P_{us,t}^*$. Results with 2SLS are not very different from results found earlier, but the theoretical implications are substantial; while $P_{us,t}^*$ is still long-run forcing on $P_{us,t}$, short run effects of $P_{us,t}^*$ are very delayed. Changes in the price on the global wheat market only reach through to the US after 7 months. Since this is not plausible it was decided to leave this option behind.

A second option that was examined was estimating both $P_{us,t}$ and $P_{us,t}^*$ as endogenous variables. This results in a VECM for the US specific model containing two equations. The results for the equation of $P_{us,t}^*$ in this VECM were very poor, where almost all parameters were not significant. Hence, this method did not seem appropriate.

Chudik and Smith (2013) explore the idea that in some GVAR models it might not be realistic to assume all countries to be small economies relatively to the rest of the world. In their paper, they assume that the US is a global dominant economy, which implies that shocks in small economies have insignificant effects on the price in the US while shocks in the US can have a significant impact on the prices in all countries. They show that the general restrictions used originally in a GVAR model are no longer valid in the presence of such a dominant economy. Underpinned by theory, a new methodology is proposed; the restrictions are relaxed and variables of the dominant economy are added to the set of foreign variables that are included in the individual country models. This implies that the domestic variables of the US are taken into account in all the other country models in two ways: (1) indirectly in the weighted average star variables and (2) directly by adding the domestic US variables in all the other country-specific models. The model for the US remains the same, except for the fact that the foreign star variables that are not weakly exogenous were excluded from the country-specific model of the US. Chudik and Smith (2013) compare this model with a benchmark model, similar to Dees et al. (2007a), where the foreign star variables that are not weakly exogenous were also excluded from the country-specific model of the US but where the other country-specific models were not augmented with US variables. They find significant differences in the generalized impulse response function analysis when they compare these two models, which implies that assuming a country to be dominant or not is key in analysing the international linkages among countries globally.

The study of Chudik and Smith (2013), but also that of Dees et al. (2007a), provides a possible answer to the fact that the US does not fulfil the requirements of a small economy in our model. If we follow Dees et al. (2007a), the foreign star variables that are not weakly exogenous will be left out from the model. Following Chudik and Smith (2013) would mean an additional augmentation of the other country specific models with US domestic variables, to represent its global dominance affecting the domestic markets.

Since the model of the US, as well as the other country-specific models, only includes one star variable, P_{us}^*, both alterations will have significant impacts for our model. It will not particularly impact the methodology, since the model will still be solvable, but it does impact the theoretical interpretation significantly. Since P_{us}^* is the only star variable included in the US specific model, removing this variable will remove all the possible influences of the prices in the other countries on the US price. This implies that the US price will only be influenced by the domestic variables and the oil price, but not by any of the variables of the other countries. If we follow Chudik and Smith (2013) and include US variables as foreign variables in the other country-specific models the assumption becomes even stronger; the US variable has a direct impact on the domestic prices in the other countries (and also an indirect effect through the country-specific star variables).

Assuming that the wheat prices in the four other countries do not have any impact on the domestic wheat price of the US seems not appropriate. Whether or not a country is assumed to be a 'small economy' is related to the global market share relatively to the rest of the world of that country, i.e. the share of total exports. Over the period of 2009-2011 US' wheat exports accounted for 31% of the total wheat exports of the five countries included in this model. Even though this is the largest share among these five countries, this share is not exceptionally high (Europe's share accounts for 23%, the share of Canada is 21%, Australia 18% and Argentina 7%). With this information, it is inconceivable to assume that these countries do not affect the US price at all and that the US is dominating the global wheat market. Therefore, we conclude that following Chudik and Smith (2013) or Dees et al. (2007a) is not appropriate for our model structure.

Since this analysis did not result in a reliable and appropriate measure to solve the problem of rejecting the weak exogeneity assumption of the star variable of the US we decide to continue with the estimation results presented in table 5.

5. Solving the GVAR

The various country equations are linked via the constructed foreign prices, which are weighted averages of all other countries prices. So, the various prices appear in all equations either as dependent variable, or as part of the weighted foreign price. Following Pesaran (2004), all equations are then stacked into one system, and solved for the domestic prices. This yields the following structure for the solved GVAR:

$$P_{ar,t} = 13.082 + 1.157P_{ar,t-1} + 0.232P_{au,t-1} - 0.069P_{ca,t-1} + 0.290P_{eu,t-1} - 0.039P_{us,t-1} - 0.325P_{ar,t-2} - 0.165P_{au,t-2} + 0.196P_{ca,t-2} - 0.176P_{eu,t-2} - 0.080P_{us,t-2} - 0.112P_{ca,t-3} + 0.101P_{us,t-3} - 65.146\,ER_{ca,t} + 60.391ER_{ca,t-1} + (0.368 - 0.637)PO_t + (-0.368 + 0.556 + 0.009)PO_{t-1} + 1.225\,\varepsilon_{ar,t} + 0.695\varepsilon_{au,t} + 0.657\varepsilon_{ca,t} + 0.776\varepsilon_{eu,t} + 0.897\varepsilon_{us,t} \tag{5}$$

$$P_{au,t} = 27.833 + 0.073P_{ar,t-1} + 1.216P_{au,t-1} - 0.064P_{ca,t-1} + 0.229P_{eu,t-1} - 0.045P_{us,t-1} - 0.058P_{ar,t-2} - 0.350P_{au,t-2} + 0.161P_{ca,t-2} - 0.145P_{eu,t-2} - 0.066P_{us,t-2} - 0.092P_{ca,t-3} + 0.083P_{us,t-3} - 53.499\,ER_{ca,t} + 49.595ER_{ca,t-1} + (0.783 - 0.523)PO_t + (-0.783 + 0.457 + 0.007)PO_{t-1} + 0.218\,\varepsilon_{ar,t} + 1.478\varepsilon_{au,t} + 0.539\varepsilon_{ca,t} + 0.637\varepsilon_{eu,t} + 0.736\varepsilon_{us,t} \tag{6}$$

$$P_{ca,t} = 23.817 + 0.173P_{ar,t-1} + 0.435P_{au,t-1} + 0.539P_{ca,t-1} + 0.544P_{eu,t-1} - 0.050P_{us,t-1} - 0.128P_{ar,t-2} - 0.300P_{au,t-2} + 0.588P_{ca,t-2} - 0.321P_{eu,t-2} - 0.145P_{us,t-2} - 0.336P_{ca,t-3} + 0.185P_{us,t-3} - 195.170\,ER_{ca,t} + 180.926ER_{ca,t-1} + (0.670 - 1.909)PO_t + (-0.670 + 1.666 + 0.016)PO_{t-1} + 0.483\,\varepsilon_{ar,t} + 1.265\varepsilon_{au,t} + 1.967\varepsilon_{ca,t} + 1.413\varepsilon_{eu,t} + 1.632\varepsilon_{us,t} \tag{7}$$

$$P_{eu,t} = 17.126 + 0.115P_{ar,t-1} + 0.287P_{au,t-1} - 0.108P_{ca,t-1} + 1.395P_{eu,t-1} - \tag{8}$$

$$0.080P_{us,t-1} - 0.092P_{ar,t-2} - 0.216P_{au,t-2} + 0.257P_{ca,t-2} - 0.416P_{eu,t-2} - 0.105P_{us,t-2} - 0.147P_{ca,t-3} + 0.133P_{us,t-3} - 85.300\,ER_{ca,t} + 79.074ER_{ca,t-1} + (0.482 - 0.834)PO_t + (-0.482 + 0.728 + 0.012)PO_{t-1} + 0.347\,\varepsilon_{ar,t} + 0.909\varepsilon_{au,t} + 0.860\varepsilon_{ca,t} + 1.833\varepsilon_{eu,t} + 1.174\varepsilon_{us,t}$$

$$P_{us,t} = 21.122 + 0.150P_{ar,t-1} + 0.377P_{au,t-1} - 0.108P_{ca,t-1} + 0.472P_{eu,t-1} + 0.641P_{us,t-1} - 0.113P_{ar,t-2} - 0.266P_{au,t-2} + 0.317P_{ca,t-2} - 0.285P_{eu,t-2} - 0.190P_{us,t-2} - 0.181P_{ca,t-3} + 0.242P_{us,t-3} - 105.190\,ER_{ca,t} + 97.513ER_{ca,t-1} + (0.594 - 1.029)PO_t + (-0.594 + 0.898 + 0.021)PO_{t-1} + 0.428\,\varepsilon_{ar,t} + 0.121\varepsilon_{au,t} + 1.060\varepsilon_{ca,t} + 1.253\varepsilon_{eu,t} + 2.140\varepsilon_{us,t} \quad (9)$$

Equations (5-9) show that every country-specific domestic price is not explained anymore by the country-specific foreign prices, the star variables, but solely by the other variables included in the model and their lags. The variables that are included in these equations are the variables that explained $P_{i,t}$ and those that indirectly explained $P_{i,t}^*$. For example, the equation for the domestic price of Canada was determined by an expression that included $P_{ca,t-1}$, $P_{ca,t-1}^*$, $ER_{ca,t-1}$, PO_{t-1}, $\Delta P_{ca,t-1}$, $\Delta P_{ca,t-2}$, $\Delta P_{ca,t}^*$, $\Delta ER_{ca,t}$ and ΔPO_t. Since for the four other countries P_{ca} is included in their foreign price, these variables will return in every single equation. Because the parameters for the five star variables differ and the weights used are country-specific, the β_i's will have different values across the different countries. Equations (5-9) also shows the three ways in which the interactions among the countries are taking place: (1) the dependence of $P_{i,t}$ on the explanatory variables of $P_{i,t}^*$, (2) the dependence of $P_{i,t}$ on the common variable (the oil price) and (3) the weakly dependence of $P_{i,t}$ on the country-specific shocks ($\varepsilon_{i,t}$).

6. Impulse Response Analysis

Using equations (5-9) effects of a shock in one of the variables on the five domestic prices can be analysed. Besides the direct effect of a shock in one of the included variables on the domestic prices of wheat, $P_{i,t}$, this system is also suitable to analyse the effects of such a shock over time via impulse response analysis. The contemporaneous effects are rather simple to interpret; the effects of a shock in one explanatory variable on one of the domestic prices can be read directly from the parameters. For example, equations (5-9) show that a positive shock at time t-1 in the Australian wheat price, due to e.g. a drought, will have the strongest effect on the domestic price of Canada while it has the least effect on the domestic price of Argentina at time t.

To analyse the effects of shocks in subsequent time periods, generalized impulse response functions (GIRFs) can be used. Building on Koop et al. (1996), Pesaran and Shin (1996) develop GIRFs, which are impulse response functions that are invariant to the ordering of the variables. Since the ordering of the variables should be determined on theory or priori information, which is difficult to realize in such a complex model as a GVAR, using GIRFs is preferred (Pesaran and Smith, 2006b).

Figure 2 shows the response of the five wheat export prices to a one standard deviation positive shock in the Australian wheat price. The last three months of 2009 were used as input data for the wheat export prices, while the data of for the exchange rates and the price of oil are used for the whole simulation period since these variables are determined exogenously. Subsequently, a positive one standard error shock in the Australian wheat price in the first month of 2010 (period 1) is simulated, which corresponds to a price increase of 24.8% compared to the baseline scenario.

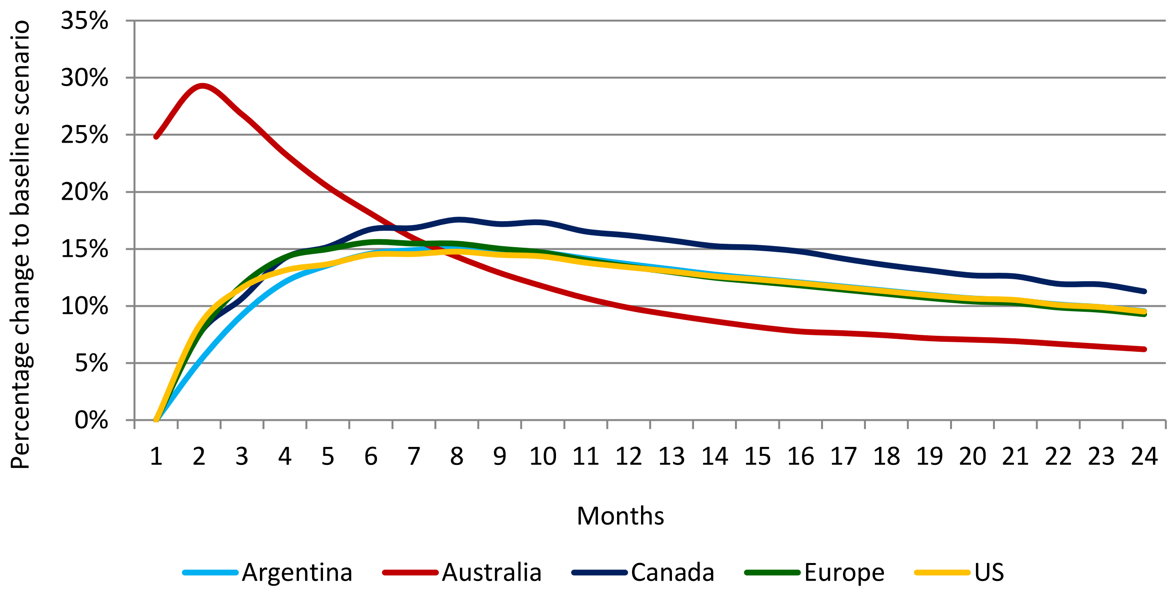

Figure 2. Impulse response of wheat export prices to a positive Australian wheat price shock

Figure 2 shows the development of this shock among the different wheat export prices over 24 months compared to a baseline scenario. The Australian price peaks at 29.3% in the second month. Unsurprisingly, all the other export prices also increase. The strongest effect is seen in the Canadian wheat price, which peaks at 17.6% 7 months after the shock was introduced. This was expected, given that the Canadian export price reacts strongest on changes in the foreign prices. In the case of Argentina, Europe and the US, prices increase around 15% at most, showing that the shock has less impact on these countries. Remarkable is that the effect of the shock after 2 years is more pronounced in the other countries than in Australia itself.

In comparison, the same procedure is performed for a positive shock in the Argentinian wheat price, where a positive one standard deviation shock is corresponding to a price increase of 32.4% compared to the baseline scenario. The results are shown in figure 3. The largest effect is again shown in Canada, where prices peak at 9% after 5 months, while the effects are most modest in Australia.

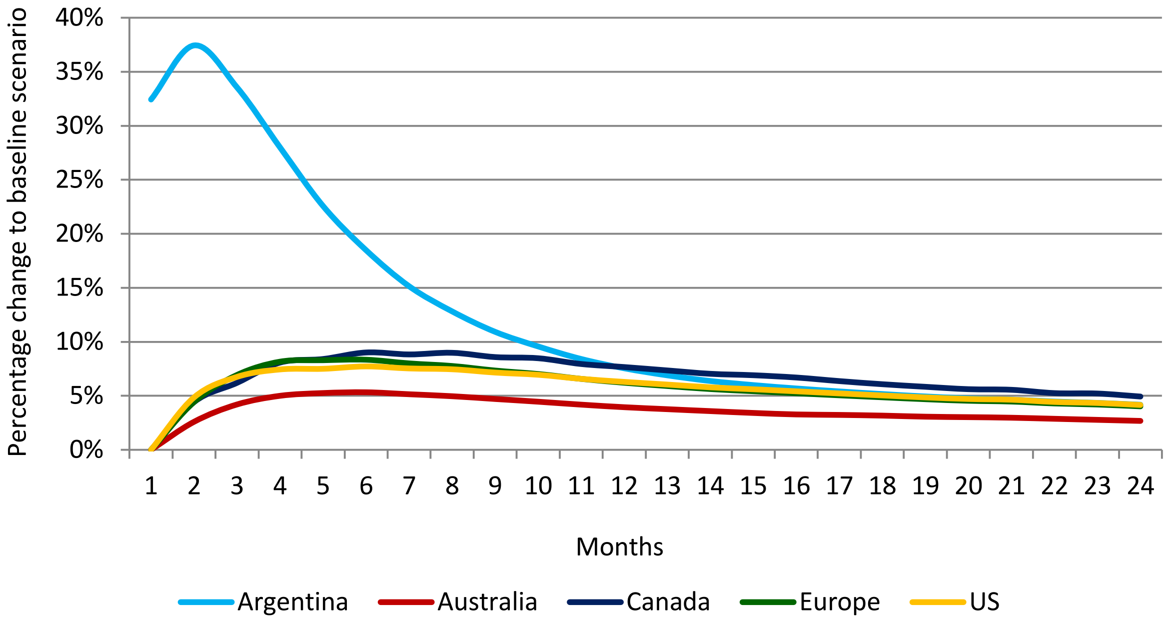

Figure 3. Impulse response of wheat export prices to a positive Argentinian wheat price shock

When comparing figures 2 and 3 it is clearly visible that a shock in the Australian wheat price has a stronger effect on the prices in the world than a shock in the Argentinian wheat price does. This was expected, given the fact that for all countries the weight assigned to Argentina is the lowest out of the four. These procedures can be performed for all the variables in the model, including the exogenous variables. This way the GVAR modelling approach provides a tool to analyse the implications of different shocks and their impact across countries and over time.

7. Conclusions and discussion

This paper presented a small GVAR model for analysing interdependencies in global wheat prices. The model included wheat export prices, the exchange rates and the oil price. There is no evidence found that the exchange rate plays a significant role in explaining the domestic wheat prices, except for Canada. Moreover, it was found that the oil price does not play a role in determining the Argentinian and European wheat price, while it does play a role in determining the Australian, Canadian and the US wheat price. The weighted foreign wheat prices had varying effects on the domestic wheat prices, with the smallest effect for Australia and the largest effect for Canada.

An important assumption in GVAR models is that none of the countries has a price dominating the foreign price, implying that the foreign prices are weakly exogenous. However, it was found that this does not hold for the US price. Various solutions were considered, but this remains an issue for further research. Another important element of GVAR models is the choice of weights in constructing the foreign variables. Here trade shares were used, but this is a subjective choice and the sensitivity of the results to these weights could be tested. In order to analyse the pros and cons of the GVAR approach it was chosen to include only five countries. However, one of the promises of GVAR modelling is that it is an approach suitable for connecting multiple countries, which would not be possible in a standard VECM. Therefore, another extension to this model would be to include more countries.

References

Bussière, M., A. Chudik and G. Sestieri (2009). "Modelling global trade flows: results from a GVAR model." European Central Bank working paper 1087.

Chudik, A. and Pesaran, M. H. (2016) Theory and practice of GVAR modelling. *Journal of Economic Surveys* 30(1): 165-197

Chudik, A. and V. Smith (2013)."The GVAR approach and the dominance of the US economy". Working Paper No. 136. Federal Reserve Bank of Dallas, Globalization and Monetary Policy Institute.

de Gorter, H. (2008). Explaining agricultural commodity price increases: The role of biofuel policies. Paper presented at the Oregon State University conference on rising food and energy prices: US food policy at a crossroads, Corvallis, Oregon.

Dees, S., F. Di Mauro, M. H. Pesaran and L. V. Smith (2007a). "Exploring the international linkages of the euro area: A global var analysis." J*ournal of Applied Econometrics* 22(1): 1-38.

Dees, S., S. Holly, M.H. Pesaran, L.V. Smith (2007b). "Long-run macroeconomic relations in the global economy ." *Economics, the Open Access, Open Assessment E-journal*, Kiel Institute for the World Economy, vol.1(3).

di Mauro, F. and L. V. Smith (2013). The basic GVAR DdPS model The GVAR handbook: structure and applications of a macro model of the global economy for policy analysis. Oxford University Press 12-34.

FAOSTAT (2014), http://faostat3.fao.org/faostat-gateway/go/to/download/T/*/E.

Garrat, A. K. Lee, M.H. Pesaran and Y. Shin (2006). "Global and national macroeconometric modelling: a long-run structural approach". Oxford University Press: Oxford, UK.

Gutierrez, L. and F. Piras (2015). "A global vector autoregresion model for the analysis of wheat export prices. *American Journal of Agricultural Economics* 97(5): 1494-1511.

Headey, D. (2011). "Rethinking the global food crisis: the role of trade shocks." *Food Policy* **36**(2): 136-146.

Headey, D. and S.G. Fan (2008). "Anatomy of a crisis: the causes and consequences of surging food prices." *Agricultural Economics* **39**(3): 375-91.

International Financial Statistics (2014), IMF eLibrary –Data http://elibrary-data.imf.org/.

International Grains Council (2012). “World Grain Statistics 2012.” London.

Koop, G., M. H. Pesaran and S. M. Potter (1996). "Impulse response analysis in nonlinear multivariate models." *Journal of Econometrics* **74**(1): 119-147.

Mitchell, D. (2008). "A note on rising food prices". Policy Research Working Paper No. 4682. The World Bank, Washington, DC.

Pesaran, M. H., T. Schuermann and S.M. Weiner (2004a). "Modeling regional interdependencies using a global error-correcting macroeconometric model." *Journal of Business & Economic Statistics* **22**(2): 129-162.

Pesaran, M.H., T. Schuermann and S.M. Weiner (2004b). Rejoinder. J*ournal of Business & Economic Stasticitics* **22**(2): 175-181.

Pesaran, M. H., D. Pettenuzzo and A. Timmermann (2006a). "Forecasting time series subject to multiple structural breaks." *Review of Economic Studies* **73**(4): 1057-1084.

Pesaran, M. H. and R. Smith (2006). "Macroeconometric modelling with a global perspective." *Manchester School* **74**: 24-49.

Pesaran, M. H. and Y. Shin (1998). "Generalized impulse response analysis in linear multivariate models." *Economics Letters* **58**(1): 17-29.

Piermartini, Roberta and Robert Teh. (2005). "Demystifying Modelling Methods for Trade Policy." WTO Discussion Paper 10 (September), World Trade Organization, Geneva.

World Bank Commodity Price Data (Pink Sheet) (2014), www.worldbank.org/prospects.