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AGGREGATE MODEL ANALYSIS OF EXOGENOUS RISK AND PRICE VARIABILITY

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(Note by the Secretariat)

This paper is part of the project on risk management in agriculture. It also contributes to different pieces of work on price volatility that have been undertaken recently by the Secretariat with an analysis of the contribution of different exogenous risk factors to price volatility using the AGLINK-COSIMO model.

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AGGREGATE MODEL ANALYSIS OF EXOGENOUS RISK AND PRICE VARIABILITY: INTERIM REPORT

Introduction

1. Price variability[1] is a major source of risk for farmers. The holistic approach to risk management in agriculture (OECD, 2009a) has framed this risk in the context of other sources of risk and the whole set of instruments and strategies used by farmers. When measured at aggregate or market level, prices show much larger variability than production. However there is evidence that at the individual farm level yield variability is typically at least as significant as prices [TAD/CA/APM/WP(2009)30/FINAL]. This farm level analysis of risk has also shown that correlations between different sources of risk and diversification of activities significantly reduce the impact of price variability on income variability. It provided good policy insights on the relevance and overlaps of different tools and policies for risk management in the farm. The five country studies in Thematic Review on Risk Management have analysed the whole set of policies and institutions that deal with risk in these countries. This has allowed providing specific policy lessons based on experiences in these countries.

2. The scoping paper for the project on risk management [TAD/CA/APM/WP(2009)3] defined a third area of work on aggregate model analysis of price volatility. The rational for this component was the fact that price risk is not coming directly from nature but from markets. Market price volatility is the main contributor to price risk at the farm level. Price risk has an aggregate market dimension that has not been covered by the micro level analysis. Market prices are determined by supply and demand forces and market adjustment processes. There are exogenous factors that contribute to generate shocks in the commodity markets, shocks that create price variability or volatility. There can also be price variability associated to the dynamics of the market adjustment process (Femenia and Gohin, 2009).

3. The recent economic crises and the so called food crisis have been associated with important variations in the prices of agricultural commodities. In that context, the volatility of commodity prices has become a rising concern for government and all actors along the food chain. The analysis of efficient policy responses to price volatility goes beyond their risk management implications. This is why three consecutive questions are being analysed in several pieces of recent and on-going OECD work on price volatility: Has volatility increased as compared to historical levels? [TAD/CA/APM/WP(2010)33] and (OECD 2010b). What are the main elements that can explain this volatility? [TAD/CA/APM/WP(2010)18]. What is the most appropriate policy response? [TAD/CA/APM/WP(2010)9], [TAD/CA/APM/WP(2010)36] and (OECD 2009).

4. This paper tackles some aspects of the second question about the factors explaining price variability. It attempts to quantify how the variability of an exogenous set of factors (shocks in yields, prices of oil and fertilisers, and some macroeconomic variables) may contribute to the observed volatility of commodity prices[2]. The impacts of policies and the dynamic adjustment effects are not directly tackled

1 In this paper, the terms variability and volatility of prices are used as synonymous.

2 This paper focuses on the inter-annual volatility of prices. Intra-annual volatility is not analysed.

in this paper.[3] To what extent can exogenous shocks in the markets explain the observed variability in the past? And then, what is left to be explained by other factors?

5. The scope of the work remains illustrative and descriptive in purpose due to the complexity of quantitative analyses that link exogenous variability with the subsequent response and adjustment of commodity markets. This linkage requires a modeling structure that is provided by the AGLINK-COSIMO model, and therefore the results are associated with the specific characteristics of this model. The partial stochastic simulations' capabilities of the AGLINK-COSIMO model are used to simulate exogenous shocks and measure price variability for some crop commodities. This variability is then compared to observed measures calculated in the statistical analysis of price volatility carried out in [TAD/CA/APM/WP(2010)33].

6. Valenzuela *et al.* (2007) used partial stochastic analysis to validate a Computable General Equilibrium model based on its ability to reproduce observed price volatility in agricultural markets. They find that their GE model does a good job in predicting volatility in some markets, but not so well in others, and use these results to guide the improvements that are needed in their model. The work presented in this paper has similarities with this approach. However it does not focus on the validation[4] of the AGLINK-COSIMO model but on the analysis of the different sources of commodity price variability.[5]

7. It is shown that while exogenous factors such as yields, crude oil and fertiliser prices as well as macroeconomic developments are not responsible for all potentially observed price variability, they do contribute to an important share of it. Different sets of specific circumstances, in terms of shocks and correlations in the shocks, are found to be crucial in determining the levels of price volatility. High volatility can exceptionally occur due to exogenous shocks if they happen to occur in specific patterns. The paper is organised in five sections: section 1 explains the methodological approach that has been followed; section 2 presents results in terms of marginal contributions to price volatility; section 3 discusses total impacts on volatility; and section 4 focuses on specific scenarios.

1. Methodology for studying price variability with the AGLINK-COSIMO model

8. The aim of the empirical work undertaken in this document is to identify and quantify the share of the observed variability in output prices that can be explained by different sources of exogenous variability using the AGLINK-COSIMO model. The AGLINK-COSIMO modeling framework provides both a well accepted partial equilibrium model and a forward looking database including long standing historical time series of supply, demand and prices for agricultural commodities. Agricultural commodity markets within this structure respond to changes in the macroeconomic environment and exogenous demand/supply shocks.

9. The AGLINK-COSIMO model is not meant to be simulated backward and hence, forward stochastic simulations are implemented to analyse commodity price variability in the medium term if the patterns of some exogenous shocks continue in the future. This is not the optimal option to analyse the extent of past volatility explained by exogenous shocks, but it is the only alternative offered by the chosen

3 The discrepancy between observed and simulated price variability is certainly related to those potential additional sources of variability.

4 This partially stochastic exercise has however been thought as a good complement to the AGLINK review currently underway and as an interesting tool to validate the model and to guide improvements to some of its components in the future.

5 This analysis does not provide any assessment of risk management policies; it focuses on understanding some determinants of price volatility.

modelling structure.[6] It is however valid for the purpose of the current paper given that the structural properties of the model remain in the forward simulation. The study under [TAD/CA/APM/WP(2010)34] proposes the analysis of structural changes and complements the current analysis. Partial stochastic simulations have already been undertaken in the past when developing the baseline projections generated for the annual *OECD-FAO Agricultural Outlook*. The 2007 and 2008 *OECD-FAO Agricultural Outlook* publications (OECD, 2007a and OECD, 2008b) included the results of some partial stochastic simulations based on yields and macroeconomic variables. Those analyses have shown how commodity price projections could deviate from baseline projections and thus have widened the range of relevance of Outlook results.

Box 1. Inferring stochastic distributions from historical variability

A statistical analysis of historical data for the main exogenous sources of risk within the AGLINK-COSIMO database and modeling framework was undertaken to define the most appropriate random distributions to represent the partial stochastic scenarios. In order to define the distributions that better simulate this variability the following methodology was applied:

Yields

Six distinct geographic zones were defined: Africa, Asia, Europe, North-America, Oceania and South America. It was assumed that climatic conditions between those zones are not correlated. Within the zones, yields for coarse grains, rice and wheat were modeled using truncated multivariate normal distributions for the first difference in yields to take the long term trend into account. The distributions were truncated in both extremes because yields cannot outreach certain limits.[7] The methodology developed for the present analysis does not allow price effects on yields. This differs from the standard modelling of yields within AGLINK-COSIMO where market prices have an impact on yield evolutions in some countries. The stochastic framework mainly focuses on reproducing observed yield variability.

Crude oil and fertiliser prices

For similar reasons, crude oil prices are simulated using a truncated normal distribution. The international fertiliser in the model is explained primarily by the movements in crude oil prices.

Macroeconomic variables

AGLINK-COSIMO is a partial equilibrium model which means that there is no feedback from the rest of the economic sectors to the model. In that context, a simple macroeconomic model for GDP changes and consumer price indices in major economies was also developed and calibrated over historical data. The crude oil price being one of the variables of this simple model, random draws for macroeconomic data are obtained by solving this macroeconomic model on the crude oil prices random draws. Technical details are available in the Annex of the document.

10. The empirical methodology used in this paper builds on these modeling efforts and further enhances the ability of performing partial stochastic simulations with the AGLINK-COSIMO model. However the focus of this paper is not to show the uncertainties associated with the projections of the 2010-19 OECD-FAO Agricultural Outlook, but to analyse the volatility generated by the exogenous variables in the model. There are obviously serious limitations to this work, not only because there are other sources of variability[8], but also because there is empirical uncertainty on the estimation of the

6 AGLINK-COSIMO is used to generate medium term projections. The policies, the parameters and the data represented in the model reflect the most recent information on commodity markets. Simulating the model backward would imply an enormous amount of work on the model to replicate how markets have actually moved in the past and the policy setting of that time period.

7 There is scope for improving the representation of the distribution of exogneous shocks on the basis of historical variability as part of the stochastic modelling framework with the use of empirical multivariate distributions for example. The simulataneity of yield and price variability could also be taken into account.

8 Such as exchange rates variability for example.

parameters used in the model. This analysis is illustrative in purpose and, given that it is very demanding in terms of computing capacities, it was decided to focus on the volatility of three international crop prices: maize, rice and wheat.[9]

11. Three groups of exogenous sources of risk and variability are considered in the analysis[10]: a) crude oil and fertiliser prices; b) macroeconomic variables including GDP growth and consumption price indices for selected leading economies[11]; and c) weather and technology related variables represented by yields for the three types of crops (coarse grains, rice and wheat). The available historical information about the distribution of these variables is used to simulate the distribution of the stochastic variability in the future. This requires some technical decisions that are described in Box 1. Figure 1 describes the structure and nature of the work undertaken to use the historical variability of exogenous sources of risk to get simulated measures of price volatility. The initial step consists in defining 150 Monte-Carlo[12] stochastic draws of the different exogenous risk factors over the projection period. The joint stochastic distributions that have been inferred from historical variability (Box 1) are used to obtain the draws that define the simulated variability. Variability is measured in this paper with the same definition as in [TAD/CA/APM/WP(2010)33], that is the standard deviation over a five-year period of the logarithm of the variable in differences.[13] The variables of interest here are world reference prices expressed in nominal terms:

$$Volatility(P) = \sqrt{VAR_{t\in(t-4,t)}\ (\ln \frac{P_t}{P_{t-1}})}$$

9 The annex of the document provides definitions and sources for those prices.

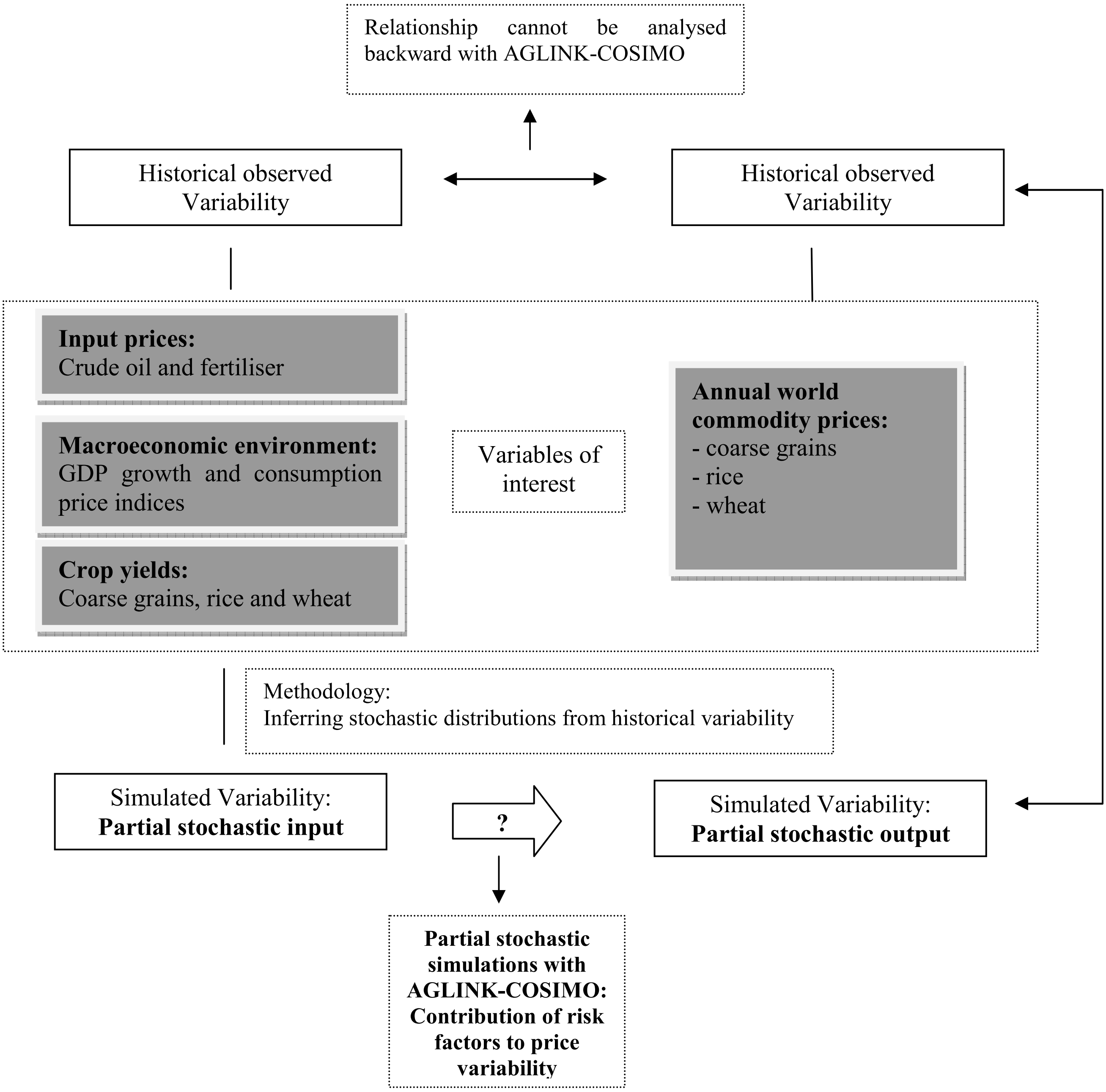
10 As part of the OECD Structural Change Project, [TAD/CA/APM/WP(2010)34] proposes with a similar partial stochastic simulations approach to analyse the impact of other factors on the world wheat price volatility: the level of global stocks, income growth effects on consumption patterns in developing countries and price stabilisation schemes. This work will complement the present study.

11 Exchange rates are not part of the group b) as their movements are very difficult to model at the global level.

12 The Monte-Carlo approach was preferred to other stochastic procedures such as the Gaussian Quadrature as it can be applied easily to dynamic recursive non linear models such as the AGLINK-COSIMO model. The number of draws was fixed at 150 for technical feasibility reasons.

13 [TAD/CA/APM/WP(2010)33] has underlined that the variability of yearly prices is generally lower than the variability of monthly prices as it hides price variations that are happening with a year. However looking at the variability of yearly market prices is important as harvests and planting decisions tend to be made on average annual prices.

Figure 1. Studying price volatility with AGLINK-COSIMO



12. Table 1 summarises some descriptive statistics of the variability of the most important exogenous variables across the different draws as measured in the final year of the outlook period (2019). For instance the baseline projections for crude oil prices do not exhibit volatility towards the end of the projection period[14], but volatility can exist in some of the draws of the partial stochastic experiments. The median volatility is 14% and the 90th percentile is 35%. Variability is significantly smaller for the average yields of the different commodities in different countries. For instance, the median value of variability is 7% for maize yields in the US, but can be as large as 15% in the 90th percentile.

Table 1. Simulated variability of exogenous variables across the 150 Monte-Carlo draws as measured in outlook year 2019

		2019			
		Median	**10th percentile**	**90th percentile**	**baseline**
World coarse grains yield		2.35%	0.87%	4.99%	0%
Coarse grains yield	USA	6.7%	0.3%	14.6%	0.3%
	EU (15)	4.3%	1.6%	7.1%	0.1%
World wheat yield		1.4%	0.8%	2.2%	0%
Wheat yield	USA	5.1%	0.1%	9.6%	0.1%
	China	4.6%	0.7%	8.4%	0%
World rice yield		1.7%	1%	2.7%	0%
Rice yield	China	2.9%	1.5%	4.5%	0%
World crude oil price		14.2%	0%	35.2%	0%
World fertiliser price		11.7%	1.8%	27%	1.8%
USA GDP deflator (1=2005)		1.8%	1%	2.6%	1.9%

13. Partial stochastic simulations[15] of the AGLINK-COSIMO model consist in solving the model on each of the 150 sets of outcomes of the exogenous variables. All resolutions of the model correspond to a possible evolution of agricultural markets that differs from the baseline presented in the 2010 *OECD-FAO Agricultural Outlook*. It is then possible to calculate volatility measures for crop prices for each of those solutions of the model and to compare them with the variability of historical annual data.

14. In order to understand the impact of different sources of risk on price variability three stochastic experiments have been undertaken as defined in Table 2. Each experiment involves solving the model for a different set of 150 stochastic draws. An additional source of exogenous variability is added in each consecutive set.

14 Small variability levels are observed for other variables in the baseline projections, this is linked to the fact that projections for 2019 are medium-term projections and thus long-term stationary levels have not yet been reached.

15 The stochastic simulations undertaken in this analysis are "partial" as all sources of uncertainty are not covered in the analysis.

Table 2. Description of the three stochastic experiments

	Exogenous sources of risk	Number of stochastic draws
1st set of stochastic experiments	- Crude oil and fertiliser prices	150
2nd set of stochastic experiments	- Crude oil and fertiliser prices - Macroeconomic variables	150
3rd set of stochastic experiments	- Crude oil and fertiliser prices - Macroeconomic variables - Yields for coarse grains, wheat and rice	150

15. The first set of stochastic experiments only lets crude oil and fertiliser prices move according to their distributions. The second set of experiments is built on the results of the first set. The same 150 draws of medium-term evolution path for crude oil and fertiliser prices are matched with 150 draws for some macroeconomic variables. The third stochastic experiment is built on the second set using the same medium-term evolutions for crude oil prices, fertiliser prices and macroeconomic variables, which are matched with 150 draws for yields of coarse grains, rice and wheat. The comparative analysis in sections 3 and 4 of the price variability derived from each set of experiments allows studying the contribution of the different sources of risk to total price volatility. The relative contribution of the different sources of risk presented in the next sections is contingent to the sequence in which the shocks are introduced. However, the sequence is unlikely to change the order of magnitude of these contributions.

2. Marginal contributions of exogenous shocks on crop price volatility

16. This section looks at the marginal contributions of the different risk factors to crop price volatility.[16] Figures 2.a-c are scatter plots of partial stochastic simulations results for coarse grains, rice and wheat price volatility in 2019 as a function of respective yield variability.[17] They correspond to results of the third set of stochastic experiments. They show that there is a link between price volatility and yield variability. This seems to hold for coarse grains but relatively less for wheat and rice. This might be the case for two reasons. Binding policy mandates for biofuels use mean that whatever the global production, the demand for coarse grains from the ethanol industry will remain high. Variability in the supply of coarse grains will inevitably be translated into the world price. In addition, the inclusion of biofuels in AGLINK-COSIMO may have implied larger response of coarse grains markets to unexpected shocks on the demand and the supply sides than for other markets as the level of modeling refinement has increased.

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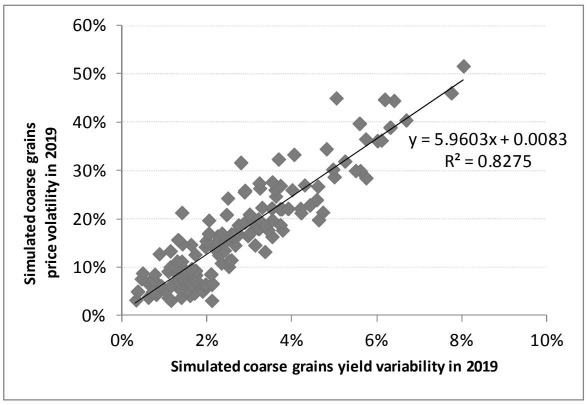
16 The crop price volatilities analysed here have been simulated with the third set of stochastic experiments (where all sources of risk are taken into account).

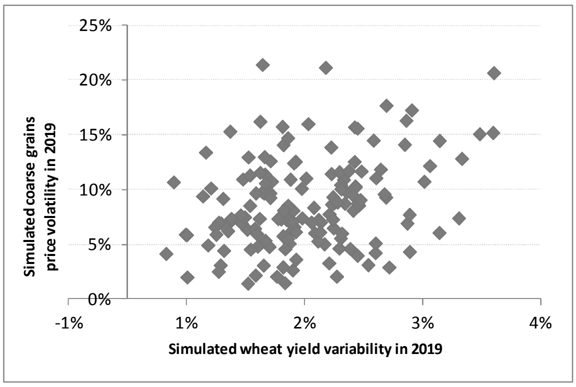
17 Yield variability is defined similarly to crop price volatility. It corresponds to the variance of commodity yield changes around their mean value for a five year period.

Figure 2 a.b.c. Stochastic simulation results on simulated price volatility

2.a. Simulated 2019 coarse grains price volatility
as a function of 2019 yield variability



2.b. Simulated 2019 wheat grains price volatility
as a function of 2019 yield variability



2.c. Simulated 2019 rice grains price volatility
as a function of 2019 yield variability

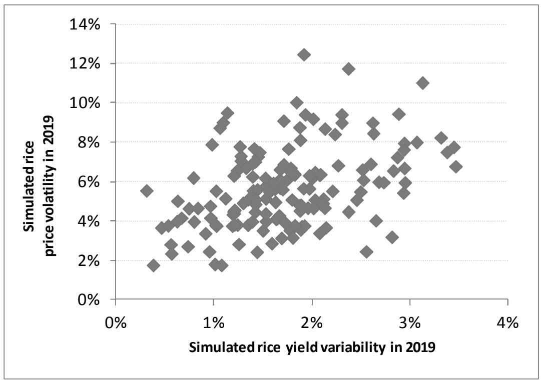


Table 3. Correlation coefficients between different simulated volatility and variability measures in 2019

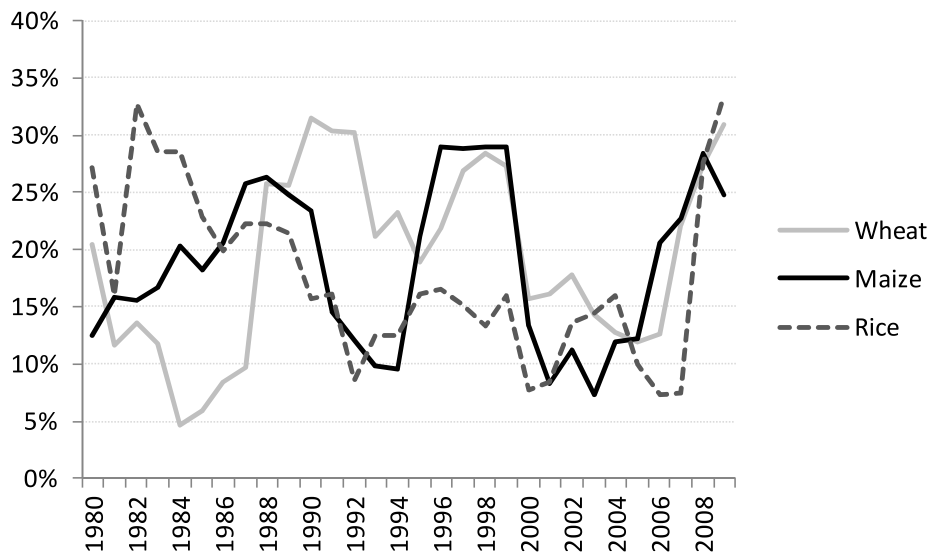
	Coarse grains Yield var.	Wheat Yield var.	Rice Yield var.
Coarse grains Price vol.	0.9	0.1	0
Wheat Price vol.	0.4	0.3	0
Rice Price vol.	0	0	0.4

17. Table 3 further illustrates this link between commodity price volatility and yield variability. The correlation coefficients between simulated price volatility measures and yield variability measures are all positive and relatively strong (between 0.3 and 0.9). Wheat markets and coarse grains market seem to be working together in terms of price volatility: the correlation coefficient between coarse grains yield variability and wheat price volatility is 0.4, larger than the correlation coefficient between wheat yield variability and wheat price volatility.

3. Total impacts of exogenous shocks on crop price volatility

18. The marginal contributions of different sources of exogenous variability to price volatility combine for a total effect that is captured in the simulated levels of volatility; which can be compared to the historical volatility that is analysed in [TAD/CA/APM/WP(2010)33]. Volatility was particularly large in the 1970s and particularly low in the 1960s and in 2000-2005. There has been an increase in volatility since 2007, but it is still lower than in the 1970s. Historical volatility measures are ranging between 7% and 29% for maize, 7% and 54% for rice and 5% and 40% for wheat. Figure 3 shows the historical volatility of international maize, rice and wheat prices expressed in annual nominal terms over the period 1980 - 2009 as calculated from the AGLINK-COSIMO database.

Figure 3. Historical annual volatility of international prices for maize, rice and wheat



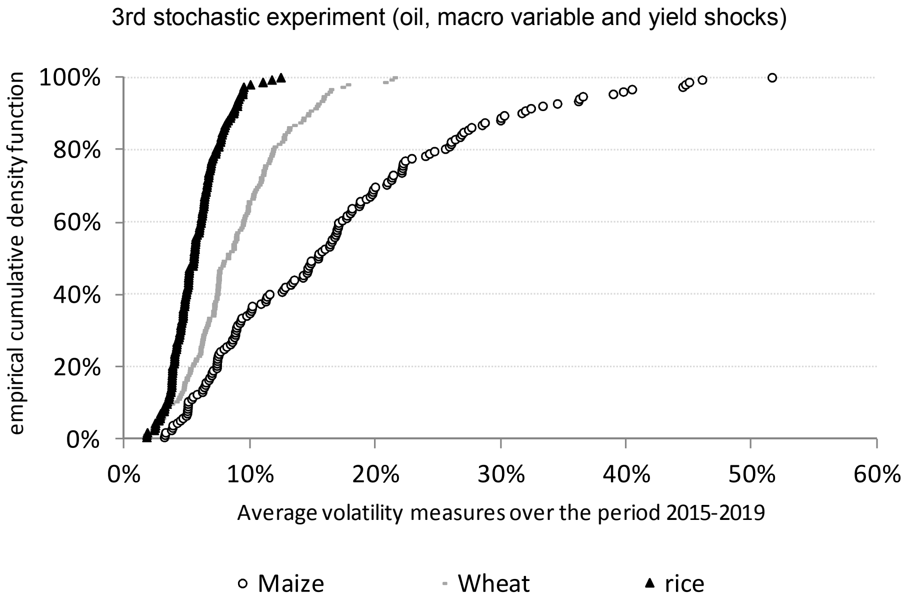
Source: AGLINK-COSIMO database.

19. The international reference price projections presented in the *OECD-FAO Agricultural Outlook* are generally not very volatile as they assume normal weather conditions, a smooth macroeconomic environment and the continuation of policies in place. That is, they do not include shocks to any exogenous assumption. This is the reason why the estimated levels of volatility in the baseline projections towards the end of the projection period[18] are rather low. This is consistent with the concept of baseline projections that attempt to capture the main trends in the markets rather than the variability around the trend. Volatility of the international maize and wheat prices in the baseline are close to 3% on average in 2019. The volatility of the international rice price is a bit lower at about 0.5%.

20. Volatilities for the world price of maize, rice and wheat have been calculated over the ten-year projection horizon for each of the 150 simulations of the three sets of stochastic experiments. The 3rd set of stochastic experiments simulates the whole set of shocks (input prices, macroeconomic variables and yields) and it is used to analyse the simulated volatility measures. Figure 4 shows the empirical cumulative density functions of simulated volatility measures for the three commodity prices. This figure provides a good illustration of the interest of carrying partial stochastic simulations to look at price volatility.

21. The range of levels of variability estimates of the different commodities can be very large when we consider 150 different outcomes of exogenous shocks. This would not be possible when analyzing volatility over a historical period as the number of observations would be much lower. Obviously all sources of risk are not taken into account here and this explains why in almost all simulations, volatility estimates for international crop prices are lower than volatility levels that have been observed over the past 30 years. However the order of magnitude is not that different, particularly for maize.

Figure 4. Cumulative density function of volatility measures for international reference prices in 2019



18 Because of the definition of volatility used in this paper, the price volatility estimates are influenced during the first five-years of the projection period by the movements of prices towards the end of the historical period. To not confuse the reader about the path of the volatility measures over the projection period, it was decided to show volatility measures for the end of the projection period, i.e. 2019 measures. The volatility observed in 2019 in baseline projections is small but slightly different from zero as the projections are made over the medium-term. In the long term, projections should be stationary and variability equal to zero.

22. The partial stochastic analysis results in higher volatility levels for maize than for wheat and rice. This ranking of volatility is broadly the opposite than in the historical estimations. Many reasons can explain why the model simulated particularly large variability of maize prices. The main one concerns the nature of the shocks:

- The simulated variability of yield shocks is higher for maize than for wheat and rice (Table 1), which will imply more responses in the coarse grains market. International maize prices respond more strongly to changes in yields because when mandates are binding[19] maize demand is more inelastic: an important share of the global maize production is used whatever the price to produce ethanol.[20]

- The crude oil and fertilizer prices have a larger impact on production costs for maize than for rice and wheat.

- GDP shocks affect maize more than rice and wheat because a much larger share of total demand is feed which is derived from meat and has a much larger income elasticity than food use for wheat and rice.

Finally, it could be that, in the case of rice, the main sources of price volatility are those that are not covered in this analysis such as stock holdings and trade policies like export restrictions (Timmer, 2009).

23. Table 4 presents the results of the three sets of experiments in terms of the median, the 10th percentile and 90th percentile of volatility estimated over the period 2015-19. As expected, volatility measures increase with the number of sources of exogenous risk taken into account. Variability of input prices and yields has the greatest impact on variability of commodity prices, well above the impact of macroeconomic variables. The distribution of the impacts seems to be skewed to the higher values of volatility, particularly for wheat and maize, which implies that the median volatility could be well below some outcomes of the experiments. In other words, there is potential for episodes of levels of volatility well above the median.

24. Table 4 also enable to compare volatility observed over the period 1976-2009 with simulated volatility from stochastic experiments: Due to the reasons that have already been cited above, the 10th percentile, median and 90th percentile of stochastic volatility in the third set of stochastic experiments for maize seem to match quite closely respectively the minimum, median and maximum volatility levels observed historically. This is not the case for rice and wheat where the stochastic volatility is much lower than historical volatility. However, it is worth to note that the comparison of simulated maize price volatility with historical volatility might be somehow biased as over the 1976-2009 period, the demand for maize to produce ethanol was much lower than what is assumed over the Outlook period.

19 As assumed in the modelling framework

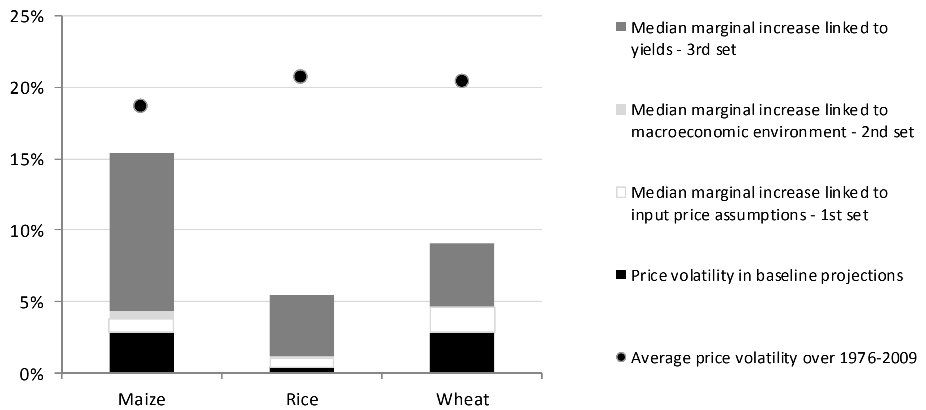
20 Gohin and Treguer (2010) have noted that price volatility could decrease on corn markets if biofuel production was greater than mandated levels. At sufficiently high crude oil prices, biofuel production in many countries could become viable even in the absence of policy support and could well exceed mandated levels.

Table 4. Simulated volatility measures in 2019 for international crop prices

		Maize	Rice	Wheat
Baseline		3%	0.4%	3%
1st set	10th percentile	2.1%	0.4%	2.1%
	Median	**3.8%**	**1.1%**	**4.6%**
	90th percentile	7.1%	2.3%	7.1%
2nd set	10th percentile	2%	0.4%	1.5%
	Median	**4.3%**	**1.1%**	**3.7%**
	90th percentile	8.1%	2.6%	8.6%
3rd set	10th percentile	5.1%	3.4%	4%
	Median	**15.4%**	**5.5%**	**8.1%**
	90th percentile	31.5%	8.7%	14.5%
Historical period: 1976-2009	Minimum	7%	7%	5%
	Median	**19%**	**16%**	**21%**
	Maximum	29%	54%	40%

24. Figure 5 shows the total median simulated variability of crop prices in 2019. These numbers correspond to the median numbers for the 3rd set of stochastic experiments as presented in Table 4. Figure 5 decomposes total impacts into cumulative contributions of the different risk factors to total price volatility. Macroeconomic factors have only a marginal contribution in all the commodities, but a bit larger in the case of maize. Input prices (oil and fertilisers) have the highest impact on the variability of wheat prices. Yield variability is the main contributor to price volatility for the three commodities, and is particularly large for maize.

Figure 5. Simulated Median price variability in 2019



4. How can episodes of very low or very high volatility happen?

25. Dewbre *et al* (2008) expressed the idea that the price spike during what was called the food crisis (2006-2008) was due to a conjunction of factors and not any single factor. In the present paper, the quantitative analysis undertaken with the AGLINK-COSIMO model seems to suggest that volatility is also not the consequence of a single risk factor. It accredits the idea that very high volatility can exceptionally occur due to exogenous shocks if they happen to follow specific patterns. The present study only focuses

on some of the factors behind price volatility but it shows that it is possible to represent plausible patterns of price volatility within an aggregate modeling framework such as the AGLINK-COSIMO model.

26. Among the 150 outlook paths under the third set of stochastic experiments, there are outcomes with very high volatility of prices and outcomes with very low volatility. Different circumstances or patterns of hazardous events can create these different levels of volatility. To illustrate this, three specific outcomes of the third set of stochastic experiments are presented in Table 5.

27. Simulation 1 presents high levels of volatility of prices of both maize (30%) and wheat (14%). This is because of a combination of circumstances in this draw such as the relatively large variability of maize yields (5%) and oil price (20%). But these circumstances alone would not be sufficient. High price volatility was to a great extent generated by the high correlation between yields of wheat and maize (75%), and a very high negative correlation between oil prices and maize yields (-54%). When production was low, it was systematically so across these commodities. At the same time, in these draws, oil prices tended to be high. The opposite was true when yields were higher than usual. It is because of this combination of rather rare circumstances in terms of coincidence of different shocks that commodity prices are so volatile in that simulation.

28. Simulation 2 shows a median level of price volatility for the world maize price and slightly higher than the median level for wheat price volatility in 2019. Crude oil prices were particularly volatile, even more than in simulation 1 (24%) but yield variability was low (2%). Simulation 2 shows a positive correlation between maize yields and crude oil prices: when maize production was low/high, crude oil prices also tended to be low/high. Under these circumstances, the impact of exogenous variability on price variability is significantly lower as exogenous factors tended to offset each others. Simulation 3 shows relatively low levels of price volatility for maize (6%)[21]. This occurs as yields and crude oil prices were not highly variable and the correlation between maize yields and oil prices was positive.

Table 5. Patterns of risk in three specific draws in Set 3

	Correlation[22] of the world maize yield with		Variability in 2019 of				
	Crude oil price	World wheat yield	Crude oil price	World maize yield	World wheat yield	World maize price	World wheat price
Simulation 1	-54%	75%	20%	5%	1%	30%	14%
Simulation 2	54%	30%	24%	2%	2%	16%	11%
Simulation 3	12%	-34%	10%	2%	2%	6%	10%

29. None of these simulations is meant to be a reproduction of observed volatility. They are shown in Table 5 as examples of possible realisations of exogenous shocks that lead to specific results in terms of volatility. They do not proof that the exogenous factors explained the observed past episodes of volatility, but they show that when shocks occur with a certain plausible pattern, these specific volatility levels can potentially be observed in the markets as represented in the model.

21 This volatility level is higher than the volatility embedded in baseline projections where "normal" weather a smoothed evolution of the macroeconomic environment and of crude oil prices are assumed.

22 The correlations have been estimated over the projection period (2010-19). They correspond to correlations of variables expressed in levels.

Conclusion and further steps

30. This work has been able to simulate the impacts of different sources of exogenous shocks on the simulated inter-annual variability of crop prices with the AGLINK-COSIMO model.[23] Some interesting conclusions can be inferred:

1. Yield variability has a strong marginal effect on price variability according to the AGLINK-COSIMO model. The correlation between yield and price variability across different experiments is as high as 90% for maize. This correlation is weaker for wheat and rice.

2. Despite the limited number of sources of variability considered in the simulations, shocks on the main exogenous variables in the model are able to explain a significant share of historical price variability[24]. This is particularly the case for maize for which the set of simulations in the model are able to replicate levels of volatility that cover the whole range of historically observed price volatilities in the period 1976-2009. Rice is the commodity with lower share of the variability being explained by the exogenous shocks. In rice markets, policy actions are playing an important role on price volatility [TAD/CA/APM/WP(2010)9]. These policy actions are not considered in the present quantitative analysis.

3. The main exogenous factor explaining price volatility is yields. The price of inputs (oil and fertilisers) very rarely contribute with more than a third of the simulated price variability. In this quantitative analysis, macroeconomic variables have only a marginal contribution to total volatility. Exchange rates have not been included to the set of macroeconomic variables being simulated stochastically.

4. The coincidence of several factors can be an important element that generates high levels of volatility. For example, high variability of yields and oil prices combined with positive correlation among the level of yields for different commodites and negative correlation between oil prices and yields.

5. The analysis presented in the document focuses on price volatility at the aggregate level. Prices at the farm level do not necessarily follow the same patterns as world prices. However market price variability is the main contributor to price risk at the farm level. In the recent past, partial stochastic simulations have been undertaken with the AGLINK-COSIMO model to widen the range of relevance of Outlook results and to identify at least partially the uncertainties embedded in the deterministic point projections. The focus of the present analysis is on the factors explaining the variability of commodity prices. This analysis has also been undertaken as an input to the process of revising and validating the AGLINK-COSIMO model as it provides good information on how the model performs.

31. This empirical analysis is just a first step in the direction of further developing the partial stochastic modelling capacities of the AGLINK-COSIMO model. Its substantive results are interesting per se. The work could be improved, for instance, with a better representation of the distribution of exogneous shocks on the basis of historical variability. Further investment on this type of analysis could be undertaken.

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23 As a complement to the present analysis, a report to be presented to the November 2011 meeting of the APM Working Party will discuss selected scenarios designed to clarify issues regarding world wheat price variability on the basis of the scoping paper [TAD/CA/APM/WP(2010)34].

24 This analysis does not attempt to explain specifically the high levels of commodity price volatility observed over the 2006-2008 period.

32. Stochastic simulations provide useful insight into uncertainties surrounding AGLINK-COSIMO baseline projections by providing multiple alternative scenarios while not implying that one of these scenarios will be the “real” outcome. There are limitations as this type of analysis cannot cover all uncertainties. The present document focuses on exogenous uncertainties linked to climate and macroeconomic evolution. There are several other sources of uncertainty in the benchmark projections. In particular, there is an empirical uncertainty on the estimation of the parameters of the AGLINK-COSIMO model and a modelling uncertainty on the endogenous dynamics of markets and agents’ expectations and risk aversion.

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ANNEX

A.1 Data

33. All historical and projection data from the OECD-FAO Agricultural Outlook 2010-2019 are available online in the Outlook website: www.agri-outlook.org.

34. Table A.1.1 provides the definitions and sources of the prices studied in the present document.

Table A.1.1. Data definitions and sources

	Definition	Source	Unit
Maize	No.2 yellow corn, US f.o.b. Gulf Ports (September/August)	Economic Research Service (USDA)	USD/t
Rice	Milled. 100%. grade b. f.o.b. Bangkok	FAO	USD/t
Wheat	No.2 hard red winter wheat. USA f.o.b. Gulf	Economic Research Service (USDA)	USD/t
Fertiliser	Fertiliser world price	FAO	USD/t
Crude oil	Short term update for crude oil price from OECD Economic Outlook No.86.	OECD-ECO / IEA	USD/barrel

NB: The fertiliser is computed using a fixed weighted combination of fertiliser component prices as published by World Bank: 20% DAP basis USA, 16% MOP (Canada), 2% TSP (USA), and 62% Urea (Eastern Europe).

A.2 AGLINK-COSIMO and partial stochastic analysis

General information

35. The present section updates the model documentation provided in OECD (2007b and 2008b). The AGLINK-COSIMO model is a partial equilibrium model of world agricultural markets. It covers annual supply, demand and prices for the principal agricultural commodities produced, consumed and traded in each of the countries represented in the model. The model treats most OECD countries and their main trading partners as individual supplying and demanding regions. Other countries are included in one of several broad regional groupings. Table A.2.1 presents an overview of the countries and regions that are modeled in the AGLINK-COSIMO framework.

36. Commodity coverage includes main temperate zones commodities as well as rice, sugar and vegetable oils. Fully integrated models for biodiesel and ethanol markets were developed in 2008 for several OECD countries as well as for a range of developing countries and added to the AGLINK-COSIMO model. An explanation of enhancements made to enable modeling of biofuels is presented in OECD (2008c). Table 2 gives an overview of the commodities which are modeled in AGLINK-COSIMO. The model assumes most agricultural commodities to be homogeneous goods traded in competitive markets.

37. The AGLINK-COSIMO model is intended for policy analysis and, as such, includes the specific mechanisms of agricultural and biofuel policy regimes in modeled countries. Domestic markets are usually tied to world markets through price transmission equations.

38. Supply and demand elasticities in AGLINK-COSIMO come from published studies and from econometric analysis undertaken by the OECD and the FAO. They have been reviewed as part of the AGLINK-COSIMO review (OECD, 2009b).

39. AGLINK-COSIMO user group meetings (with the participation of experts from government agencies or research institutes that apply the model in their own analyses) are taking place every two years to review the parameters, structure, and policy representation in AGLINK-COSIMO and to discuss specific aspects of model applications. *Ad hoc* reviews are also carried out as specific needs for baseline or policy analysis evolve.

Crop components of AGLINK-COSIMO

40. The main focus of the present study is on crop markets. The characteristics of the crop components of AGLINK-COSIMO are presented in this section.

41. Crop production is expressed as the product of area harvested and yield per hectare. Area harvested and yields are represented separately and each may be influenced by relative prices and, predominantly in the case of area harvested, government policies.

42. Complete supply and utilisation accounting of crop commodities is made in the model for wheat and rice only. On the supply side, in most modules the area, yield and production of individual coarse grains and oilseeds are represented separately. However, the demand for coarse grains and oilseeds is accounted for as separate aggregates.

43. Competition for land among alternative crops is represented in the model by cross-price effects in the area equations. More precisely, crop area depends on gross revenues for the crop in question and for competing or, in a few cases, joint commodities. Yields when endogenous, are usually represented as simple functions of prices and/or time trend variables which serve as proxies for technological change. Farm production of oilseeds is handled in the same way as farm production of cereals. Additionally, the production of the derivative products - vegetable oil and oilseed meal - is also represented. This is done through equations linking the quantity of oilseeds processed (crushed) in each country, to prices of oilseeds, vegetable oil and oilseed meal. Quantities produced of vegetable oil and of oilseed meal are expressed as the product of crush times the extraction rate (exogenous in most cases).

44. Six components of crop utilisation are distinguished in the model: domestic food use, domestic feed use, domestic crush (for oilseeds only, see section on crop supply), domestic biofuels and/ or other use (when applicable), trade and ending stocks.

45. For each country, the model contains food demand equations for wheat, for an aggregate of coarse grains, for rice and for vegetable oil, as well as for oilseeds in Japan, Korea and China. Each equation links quantity demanded to consumer price and population. Feed demand in the model adjusts with the change in feed prices and with the expansion or contraction of livestock supply.

46. For wheat and coarse grains, domestic use other than food and feed (for example biofuel use) is represented separately. Cereal stocks are modelled in one of the two following ways: for some regions, stocks are set exogenously. In other regions, stocks are a function of the domestic market price of the commodity and either domestic production, supply (production plus carry-in stocks) or total consumption.

Table A.2.1. Country coverage

Regions of the World	AGLINK-COSIMO Modelling
North America	Canada
	Mexico
	United States
South America and Caribbean	Central America - LDC
	Other South America and Caribbean
	Haiti
	Argentina
	Brazil
	Colombia
	Paraguay
	Uruguay
	Chile
	Peru
	Other South America
Europe	EU15 (Old EU member states)
	EU 12 (New EU member states)
	EU 27 (European Union)
	Russia
	Norway
	Switzerland
	Other Western Europe
	Other Eastern Europe
Asia and Pacific	Australia
	China
	Japan
	South Korea
	New Zealand
	India
	Iran
	Indonesia
	Malaysia
	Other Oceania - LDC
	Other Oceania
	Pakistan
	Middle East - other
	Philippines
	Saudi Arabia
	Thailand
	Turkey
	Ukraine
	Vietnam
	Asia Pacific - LDC
	Asia - other developed
	Bangladesh
	Asia - other
Africa	Algeria
	Egypt
	North Africa - other
	Nigeria
	Ghana
	West Africa - LDC
	West Africa - other
	East Africa - LDC
	Mozambique
	Sudan
	Zambia
	Tanzania
	Ethiopia
	East Africa - other
	Southern Africa - LDC
	Southern Africa - other
	South Africa

Table A.2.2. Commodity coverage

Aggregate	Commodities
Biofuel	Ethanol Biodiesel
Cereals	Wheat Coarse grains Maize Barley Oats Rye Sorghum Other Rice
Oliseeds	Soybean Sunflower Rapeseed Cottonseed Groundnut
Protein meals	Soybean meal Sunflower meal Rapeseed meal Cottonseed meal Groundnut meal Palm kernel meal Coconut meal
Vegetable oil	Soybean oil Sunflower oil Rapeseed oil Cottonseed oil Groundnut oil Palm oil Palm kernel oil Coconut oil
Sugar	Sugar beet Sugar cane Molasse
Meat	Beef Pork Poultry Sheep Eggs
Dairy	Butter Cheese Skim milk powder Whole milk powder Whey powder Casein

Use of the AGLINK-COSIMO model

47. The AGLINK-COSIMO model is designed and developed as a tool to perform analysis of agricultural markets and forward looking analysis of agricultural and trade policies. The baseline projections generated for the annual *OECD-FAO Agricultural Outlook* constitute a key application of the AGLINK-COSIMO model.

48. On an annual basis, data are updated and the model is rolled forward dynamically year-by-year to generate a 10-year baseline reflecting how markets could evolve given an extension of current policy (or

known changes), normal weather, trend yield growth, assumed stable macroeconomic settings, and certain other factors, such as petroleum prices. This baseline is reviewed at various formal committee meetings of the OECD and by FAO experts and provides a yardstick for subsequent forward looking policy analysis.

49. Policy analysis is usually conducted by changing a single or a set of assumptions about policy or macroeconomic variables solving the model for these new given data, and comparing the new simulation output to the baseline.

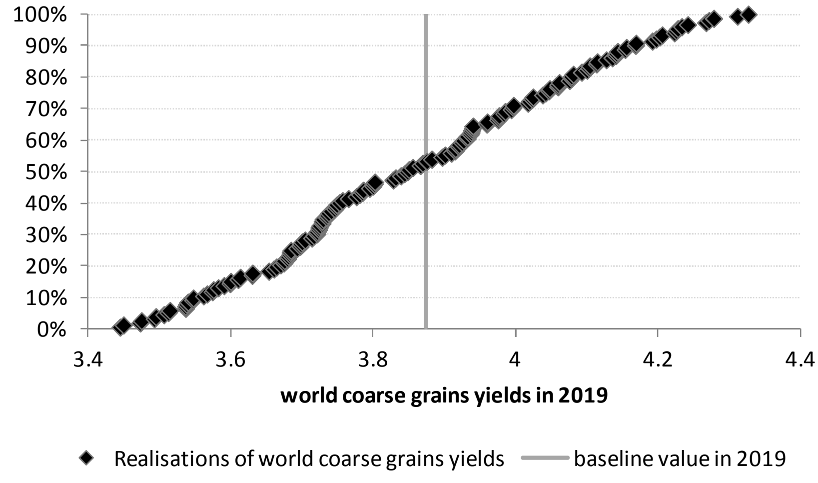
Procedures used to conduct partial stochastic simulations

Yields

50. The deterministic benchmark projections presented in the 2010 Agricultural Outlook are based on a "normal" weather assumption, *i.e.* no shock in crop yield due to weather shocks is taken into account and no assumption is made on possible climate change (*i.e.* variation from average weather). For the partial stochastic analysis, 150 different sets of crop yields for coarse grains, wheat and rice and all countries studied in the Agricultural Outlook over the coming ten years have been simulated. The methodology developed for the present analysis does not allow price effects on yields. This differs from the standard modelling of yields within AGLINK-COSIMO where market prices have an impact on yield evolutions in some countries. The stochastic framework mainly focuses on reproducing observed yield variability:

51. Six independent geographic zones have been defined. In each of the zones, variance/covariance matrices were constructed to build the multivariate distributions based on annual historical yield data between 1970 and 2009. Yields have been assumed to follow truncated multivariate normal distributions. This allows replicating over the projection period the variability of yields that has been observed over the past 40 years. As an example, Figure A.2.1 shows the empirical cumulative density function of world coarse grains yields in 2019 in the partial stochastic analysis framework. The grey line corresponds to the baseline value for those respective yields in 2019. Table A.2.1 provides descriptive statistics of Monte-Carlo simulations for world coarse grains, wheat and rice yields in 2019. There is some scope for improving the modelling of yields within the partial stochastic framework. It is envisaged to use empirical multivariate distributions instead of truncated multivariate normal distributions in future versions of the stochastic work.

Figure A.2.1. Cumulative density function of world coarse grains yields in 2019 as a result of partial stochastic simulations



Crude oil, fertiliser prices and macroeconomic variables

52. Crude oil prices are also simulated using a truncated normal distribution that has been calibrated on past historical trends. The international fertiliser price is modeled as a function of the crude oil price calibrated on historical data. A simple macroeconomic model of GDP changes and consumer price index for leading economies (Brazil, China, European Union, India, Japan, Russia and the US) was also developed and calibrated over historical data. The crude oil price being one of the variables of this simple model, random draws for macroeconomic data are obtained by solving this macroeconomic model on random draws for the crude oil price.

53. 150 sets of crude oil price, fertiliser price and macroeconomic variables projections are obtained and used as input to the model. Descriptive statistics are available in Table A.2.1.

Table A.2.1. Descriptive statistics: Monte-Carlo simulations (in levels) of risk factors in 2019

	median	10th percentile	90th percentile	baseline
World coarse grains yield	3.85	3.56	4.17	3.87
World rice yield	3.23	3.03	3.46	3.20
World wheat yield	3.28	3.15	3.40	3.24
World crude oil price	97	48	164	97
World fertiliser price	293	170	444	293
USA GDP deflator (1=2005)	1.297	1.286	1.313	1.298