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AGRICULTURAL PRICE VOLATILITY UNDER CLIMATE CHANGE

The Impact of Multiple Objectives on Commodity Prices

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Abstract

Agricultural price volatility has moved to the forefront of research efforts and political discussion, where much work is already being undertaken with respect to the impact of fluctuations in input prices (e.g. fertilizer, feed and energy). In this paper we also want to take into account the impact of climate change on prices via increased volatility in crop yields. In addition, we analyze the impact of having multiple objectives competing for the land on which crops are grown. In particular, we want to address the concerns that have been voiced about biofuel targets and calls for prioritization of food security.

Keywords: -energy, food security, food price volatility, optimization under uncertainty

JEL classification: Q12, Q18, Q28, C61, D81

1. INTRODUCTION

Over the past years policy debates in climate change mitigation have centred around the tradeoffs between different environmental and developmental objectives: the promotion of bio-fuels for climate change mitigation (e.g. in the European Union) and consolidation of energy security (e.g. in the US) has been criticized to exert additional pressure on land, which might lead to competition with efforts to store more carbon by decreasing deforestation rates. Abbot et al. (2008) also claim the diversion of food crops into the production of bio-fuels to be a reason for increased food price volatility. In a recent policy brief, Wright (2010) suggests that bio-fuel mandates in the US and the EU have contributed to food price spikes. He continues to propose the containment of such price spikes by introducing storage or through the use of “option agreements with domestic biofuel producers”, which “could guarantee voluntary diversion of grain from biofuel production [...] to targeted human consumption, in specified severe food crises” (p. 3). In this paper we will explore the second possibility in more detail.

At the same time, from the point-of-view of development, an increasing population will also add to land requirements for rising food production. From a global perspective, both climate change mitigation/energy security and ensuring food security are on the top of the agenda of policy-makers with priorities contingent on different countries’ state of development and dependency on oil imports and commitment to abatement. In general, combating malnutrition has been given precedence. Concerning the welfare-enhancing effect of food price stability, an OECD report on risk management in agriculture from 2009 warns that in practice, there are non-negligible costs associated with storage and payment programs, so the gains from food price stability need to be weighed against the costs of achieving the same. This further

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strengthens our motivation to explore possibilities to formulate bio-fuel mandates in a flexible way as suggested by Wright (2010).

Another complicating factor in such considerations is that fact that yields are volatile and that often decisions need to be made under uncertainty, the implications of which will only become apparent upon revelation of the yield scenario that eventually materializes. In a world featuring such uncertainties, food security becomes potentially even more costly to ensure and the merits of having ambitious bio-fuel mandates needs to be weighed against the additional pressure on forests and cropland needed for food production.

The model used in this paper builds on the stochastic version of the Global Biosphere Management Optimization Model (GLOBIOM), which is a global, recursive, dynamic, partial equilibrium, bottom-up model integrating the agricultural, bio-energy and forestry sectors (Havlík et al., 2011). The stochasticity emanates from different sources of uncertainty such as weather, occurrence of pests, management changes due to changes in input prices, etc, which lead to volatile yields. It is important to explicitly model this stochastically compared to the current state-of-the-art in the literature, as it has major implications for food security, which might be enforced by the need to meet certain bio-fuel mandates.

Decision-making under uncertainty has been an important branch of the economics literature over the past decades and it would go beyond the scope of this paper to review the beginnings of expected utility and prospect theory. However, it is instructive to highlight how methods to look at decision-making under uncertainty have been applied to agricultural problems to highlight our position in this literature.

Hardaker et al. (2004) and Moschini and Henessy (2001) refer to risk from yield volatility as “production risk”, which is due to unpredictable weather and performance of crops and livestock. They also differentiate it from market risks, which include price fluctuations. In this study, we take a global perspective rather than a farmer’s point-of-view, however, and also want to explore not only the impact that yield volatility has on decision-making, but also the impact that this in turn has on food price volatility if food security and bio-energy promotion are amongst the objectives of policymakers. The above-mentioned 2009 OECD report reviews the literature on risk management strategies in agriculture and divides the reviewed methods into three groups: (1) risk sharing, which spreads risk over a number of agents instead of concentrating it in one agent, (2) risk pooling, which brings together the risky returns of two or more farmers that will then share the resulting outcome and (3) diversification by using resources in different activities instead of concentrating them on a single one. These strategies all follow the idea that the overall risk can be reduced when the returns of the individual activities are not perfectly correlated. Butt et al. (2004) implement this notion in a mathematical programming based agricultural sector model, which extends the objective function to include a function of the yield variance as an additional cost. Applying their extended model to the case of Mali, they find that the model incorporating risk outperforms the model without risk consideration when comparing predicted to observed crop area.

In this study, we have to restrict ourselves to a relatively stylized approach due to the difficulty that model results become more difficult to interpret if not less meaningful if we add the variance to the objective. In the first step, we optimize under uncertainty, i.e. maximize the expected value of welfare under different scenarios of yield developments, and then in the second step observe the implications of this decision depending on the yield scenario realized, i.e. the outcomes in terms of prices and allocations and the realization of trade etc for each possible scenario. We assimilate the risk aversion to the preference of the social planner for food security in every state of the nature. A highly “risk-averse” social planner will require a minimum amount of food to be available for consumption in every state of the nature, while a “risk-neutral” one will be interested in the average value only. Furthermore, we add to the literature by exploring the impacts on food price volatility, which has been the subject of much research, which has not come to firm conclusions on the causes of unstable food prices (Gilbert and Morgan, 2010).

The model will be described in more detail in the following section. Subsequently, the scenarios for the bio-fuel targets are defined, followed by the presentation of the results. The conclusion will try to formulate some policy recommendations based on the analysis provided before and give some outlook to needs for further research in this area.

2. STOCHASTIC GLOBIOM MODEL

The stochastic version of the GLOBIOM Model introduces yield volatility into the previously deterministic framework, which is described in detail in Havlík et al. (2011). It has been used before to assess the impact of yield uncertainty on food security to look into possible adaptation mechanisms (Fuss et al., 2011) and is extended in this study to include bio-energy mandates in order to investigate the effects of such policy on prices, deforestation and other indicators, when food security is a binding constraint. If this leads to more pressure on land and thus prices, it will furthermore be interesting to explore the effects of making bio-fuel targets more flexible.

The objective function of the GLOBIOM model is the maximization of welfare, which is defined as the sum of producer and consumer surplus, subject to resource, technological and policy constraints. Prices and international trade are determined in an endogenous way for the respective 28 aggregated world regions. Product supply functions are included implicitly and are based on detailed, geographically explicit Leontieff production functions. Demand is included explicitly and elasticities are mostly constant. More detailed information on this and on the data concept and processing can be found in Havlík et al (2011).

Concerning the model structure, production comes from three major land cover types, which are cropland, managed forests and areas suitable for short rotation tree plantations. The biophysical simulation model EPIC simulates management-related yield coefficients for 17 crops, which represent more than 80% of the 2007 harvested area as reported by FAO. The management systems in EPIC are irrigated, high-input/rain-fed, low-input/rain-fed and subsistence management (You and Wood, 2006).

Supply of crops enters either consumption, livestock production or bio-fuel production. Primary forest production from traditional managed forests includes saw logs, pulp logs, other industrial logs, traditional fuel wood and biomass for energy, where the latter can be converted through combined heat and power production, fermentation for ethanol, heat, power and gas production, and gasification for methanol and heat production. Furthermore, woody biomass for energy can also be produced from short rotation tree plantations.

The model allows for endogenous change in land use within the available land resources, where the total land area is fixed over the simulation horizon. Land use change possibilities are limited in basically two ways: (1) through explicit constraints on conversion from one land use to another and (2) by linking land suitability criteria to production potentials. For details on suitability analysis, the reader is referred to Havlík et al (2011), where also all basic assumptions (i.e. exogenous parameters on population developments etc) are presented in detail.

For this paper, we do not want to reproduce the formal description of the deterministic model, but prefer to explain how stochasticity is introduced: whereas the yield for a given year in the deterministic model was given (as a matrix containing the yield for each crop, under a given crop management, in a given “Simulation Unit”); in the stochastic version the yield is modelled as a random variable having a discrete distribution with n possible different outcomes (which we call scenarios).

Some decisions have to be taken prior to the time the actual yield is observed, such as crop planting, and some are made afterwards such as the processed, traded or consumed quantities. The primary decisions thus do not depend on the particular yield scenario, but the decisions taken upon observation of the actual yield have to.

The objective function is the state-dependent variables’ expected value that is the probabilistically weighted sum of scenario-dependent producer and consumer surpluses. The decision-maker thus optimizes under uncertainty and subsequently observes the implications in terms of outcomes in the different yield scenarios or realizations of yield levels.

Note that we do not incorporate the variance or another measure of risk directly into the objective function, which solely consists of the described expected value. As explained in the introduction, risk aversion is included via the social planner’s preference, where the risk-averse planner requires a minimum amount of food to be available for consumption in every state of nature, while a “risk-neutral” (or less risk-averse) one will be interested in the average value only. This is often referred to as a safety-first constraint in the literature.

In a simplified way, the problem can be written as follows:

$$\begin{aligned} & \text{Max. } E_t \left\{ \sum_{r,y} p_{r,t,y,s} \cdot PSCS_{r,t,y,s} \right\} \\ & \text{s.t. } \sum_{r,y} p_{r,t,y,s} \cdot FC_{r,t,y,s} \geq FS_t \quad \text{for all } s \\ & \sum_s p_{r,t,y,s} = 1 \quad \text{for each } r, t, y \end{aligned}$$

where E_t denotes the expectation at time t , r and y are indices for the region and output type respectively, PSCS is the sum of producer and consumer surplus depending on the yield scenario s , FC is food consumption FS_t is the amount of food required at time t . $p_{r,t,y,s}$ is the probability of a yield scenario (state-of-nature) in a given region, at a given time and for a given crop.

We use crop yield distributions generated by the process-based biophysical Environmental Policy Integrated Climate Model (EPIC) based on future climate scenarios from the Tyndall Climate Change Centre. In particular, means and co-variance matrices were derived to subsequently generate yield distributions.

3. POLICY EXPERIMENTS ON PRICE VOLATILITY

In order to explore the questions presented in the introduction, a number of experiments have been devised, which are given in the overview in Table 1. Vertically, we increase the height of the bio-energy mandate. The bio-energy mandates are shown in Figure A.1 in the Appendix, where the global bio-energy baseline is defined according to POLES simulation results corresponding to an updated version of Russ et al. (2007).

Horizontally, we test for strictness of the policy constraint, i.e. strict FS means that the food security constraint needs to hold in all yield scenarios, while flexible FS means that it has to hold only on average and equally for BM, which stands for bio-energy mandate. There are thus 3x4 experiments the results of which are presented in the following subsections.

We also compute results for the case, which is equal to the BAU, but where bio-fuel quantities are kept at 2000 levels in order to distil the impact of introducing the food security constraint. We label this policy experiment #0.

Table 1: Policy Experiments

	strict FS, strict BM	strict FS, flexible BM	flexible FS, strict BM	flexible FS, flexible BM
BAU/2020 Quantity – POLES mix	1	2	3	4
BAU 2020 Quantity -BFP1	5	6	7	8
2 x BAU 2020 Quantity -BFP1	9	10	11	12

When bio-fuel quantities are kept at 2000 levels (policy experiment #0), there is a systematic increase of more than 2% in food prices when the safety constraint on food supply is introduced.

For “BAU/2020 Quantity – POLES mix” under “strict FS”, we see only a relatively low increase in prices in terms of absolute levels (less than 1%), as there is only a change in the composition of the mandate, but not in the total level (see Figure A.1 in the Appendix). A

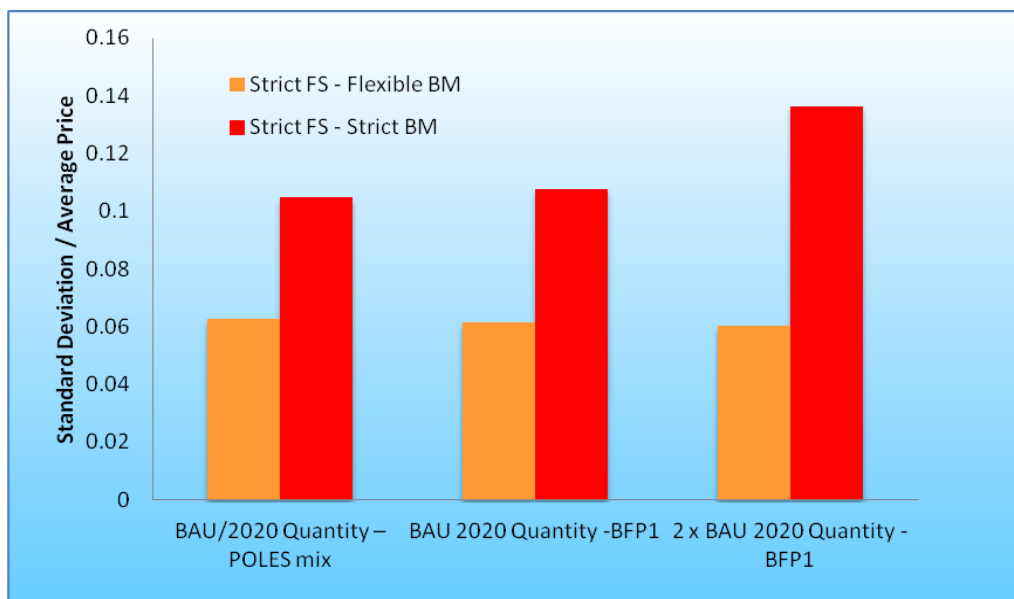
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higher increase can be observed when bio-energy mandates are more ambitious (more than 2%). However, what we are interested in is not the absolute levels, which average out price spikes and falls, but the volatility in prices and how this behaves under different policy priorities.

Therefore, we compute how the standard deviation of food price index (divided by the average price index) changes, as bio-fuel targets get more ambitious, i.e. for the three different mandate levels described above. Figure 1 below displays the results for a world where food security (FS) has priority, i.e. FS is strict. For the bio-energy mandates (BM) we have two possibilities: we once also require them to be met 100% of the time (red columns in Figure 1), but we also present a run where we require them to be met on average only (orange columns in Figure 1). In terms of Table 1, Figure 1 thus presents the results for experiments #1, 2, 5, 6, 9 and 10.

Figure 1. Price volatility when food security (FS) is a priority and bioenergy mandates flexible (orange columns, experiments #2, 6 and 10) and strict (red columns, experiments #1, 5 and 9) respectively



Source: own calculations

Two results strike us immediately: more flexibility in the bio-energy mandate (“Flexible BM” in Figure 1) allows the volatility to remain more or less constant at 0.06 for all three mandates. However, if we also require the bio-fuel target to be fulfilled in 100% of the cases, we observe that the volatility is substantially higher (exceeding 0.1 compared to 0.6 under the flexible mechanism). In addition, this trend is also increasing in the size of the mandate - the most ambitious target reaching a (normalized) standard deviation of more than 0.14.

If the food security constraint is relaxed in the same way as the bio-fuel constraint (experiments #3, 4, 7, 8, 11 and 12), the volatility is substantially lower (between 0.001 and

0.003), but a strict bio-fuel constraint still magnifies the increase from introducing an ambitious bio-energy mandate.

These findings indicate that an emphasis on food security will – next to raising the level of food prices and also their volatility - tend to make the sensitivity of food price volatility to the introduction of bio-energy mandates even higher, unless policymakers manage to introduce some flexibility into bio-energy mandates (here we need to think a bit how that could look in reality, we can make some suggestions in the conclusion).

Furthermore, another important indication of the results is more on the modelling side: in principle, the flexible bio-mandate corresponds to what a deterministic model using only the mean yields would predict (because it has to be met only on average). Thus, showing that a strict BM offers predictions substantially different from the flexible BM can be interpreted such that the stochastic model is superior to the deterministic one, since the latter does not use the full range of available information. This leads to the conclusion that it is indeed important to analyze these questions in a stochastic setting, as representing yields by their mean only, much information is lost potentially leading to inferior decisions.

Finally, our scenarios show that defining a biofuel target over several years, instead of an annual basis, could considerably decrease the volatility. Pluri-annual biofuel targets hence act as reverse storage.

3.1. Environmental Implications

In order to ensure food security, more than 10 million additional hectares of land are needed (experiment setting #0), which is mainly sourced from forests and other natural land. This is because the food constraint intends to avoid malnutrition in all cases, i.e. all yield scenarios, implying that there will be overproduction in order to fulfil the food security constraint in the “bad” scenarios. Figure 2 below shows the sum of deforested area in million hectares (Mha) when, in addition, bio-energy mandates are introduced (policy experiments #1, 2, 5, 6, 9 and 10).

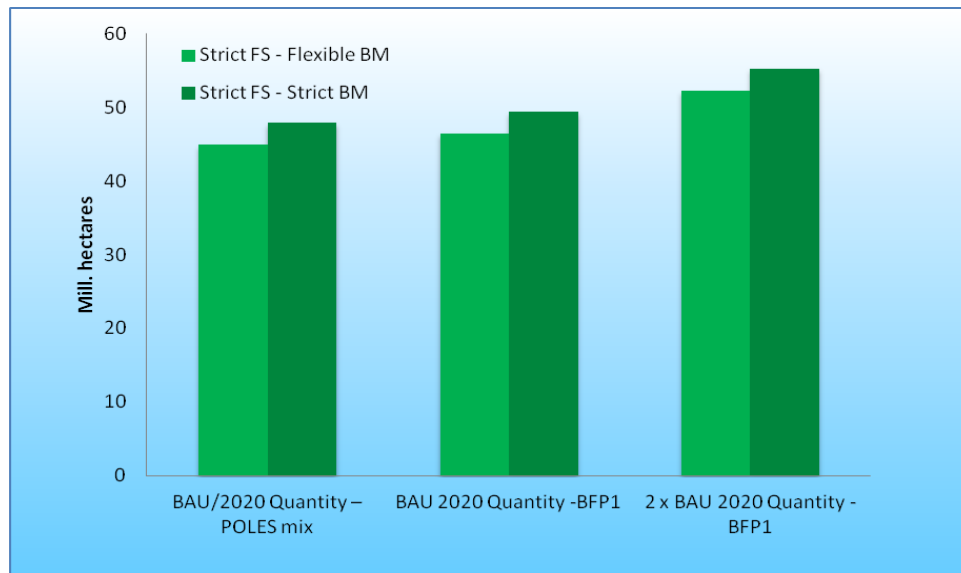
We see that the deforested area is higher (by approximately 3 Mha) when bio-energy mandates are strict and this also increases with the level of the bio-fuel target: tighter levels lead to systematically higher deforestation.

Note that if relaxed the food security constraint such that it needs to hold only on average corresponding to experiments #3, 4, 7, 8, 11 and 12, this effect of bio-energy mandates would be less pronounced. However, as food security is a priority of policymakers, allowing for more flexibility in bio-energy mandates appears to be a good option to keep both food price volatility and environmental costs in check.

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Figure 2: Sum of deforested area when food security (FS) is a priority and bioenergy mandates flexible (light green columns, experiments #2, 6 and 10) and strict (dark green columns, experiments #1, 5 and 9) respectively



Source: own calculations

4. CONCLUDING REMARKS

A deterministic global land-use model (GLOBIOM) has been extended in this study to take into account yield variability. Optimization has been carried out under uncertainty, whereupon the outcomes for each scenario given the decision under uncertainty have been computed. Two further extensions were the inclusion of a food security constraint and a bio-fuel mandate with the purpose of exploring the impacts this has on food prices, their volatility and environmental indicators such as deforestation.

The results show that prioritizing food security by requiring the safety first constraint to hold in all yield scenarios will increase the sensitivity of food prices and – even more so – of food price volatility to the imposition of bio-energy mandates. Furthermore, the effect is increasing in the height of the target. However, if bio-energy mandates are flexible and only required to hold on average, food price volatility can be kept constant, even if the food security constraint is strict.

Concerning the environmental implications, ensuring food security requires several million hectares of additional land, which is mainly sourced from forests and other agricultural land. The introduction of bio-energy mandates adds to the sum of deforested area. Making bio-energy mandates flexible, so that they would only need to apply on average and not in every scenario, would dampen the effect on deforestation considerably.

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These findings point to an important policy conclusion: enforcing rigid levels of bio-level targets might come at a severe cost in terms of enhancing food price volatility, which is already under pressure from food security, which needs to be ensured in the face of fluctuating yields. In addition, environmental implications also point to the advantages of more flexible mandates such as suggested by Wright (2010). Note that the missing, explicit representation of capacity expansions in the model implies that, in practice, producers who are considering variable cost in their individual decision-making procedure would not tend to decrease production by an equally high amount as predicted by our model runs, where the social planner considers only marginal costs. This cost discrepancy will therefore have to be taken into account in the implementation.

Moreover, while this study has focused on short- to medium-term planning, it will be important for an analysis of decisions in the long run to take into account the development of the oil price, as profit considerations will provide incentives to expand bio-fuel-generating capacity. Future research should incorporate such cross-sectoral competitive forces into the analysis.

Finally, from the modelling point-of-view, the model runs using the flexible bio-energy mandates are in principle equivalent to those from a deterministic model using average yields. The fact that the results are so different from the runs of the stochastic model (i.e. the model with strict bio-energy constraints) underlines the importance of using a stochastic setting to explore the questions posed in this paper, as otherwise decisions are based on incomplete information.

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APPENDIX: BIOENERGY MANDATES

