Working Party on Agricultural Policies and Markets

Modelling land use in Aglink-Cosimo: Scoping paper

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This paper forms part of the work mandated under Output Area 3.2.2 (Agro-Food, Trade and Development), Intermediate Output result 1.2 (Aglink-Cosimo Model Development) of the PWB 2015-2016. The developed model extensions will inform Intermediate Output 1.5 (Market and policy scenarios) which was presented to the 65th session of the Working Party on Agricultural Policies and Markets [TAD/CA/APM/WP(2015)4], in particular [TAD/CA/APM/WP(2015)28] (Biofuel Policy Reforms) which is also presented to the 66th session.

This paper presents a proposal to extend the representation of land use in the Aglink-Cosimo model. This investment should have multiple pay offs for future model analysis as it will allow to explicitly address land use questions and outcomes in any future model application.

The proposed system has been implemented for the US module of Aglink so far. In the next step it will be extended to all Aglink countries. There will be opportunities for consultation at the Commodity Group meeting, and later at the 2016 Aglink-Cosimo Users’ Group meeting. A presentation of the methodology at the World Outlook Conference in 2016 is also foreseen. The final specification will be added to the Aglink-Cosimo model documentation by November 2016.

The content of this paper has been discussed with experts within the OECD and reviewed by an external expert, Professor Brian Revell of Harper Adams University (United Kingdom). However, since the choice of the system has major implications for future analyses, further comments from technical experts in the capitals would be welcome.

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MODELLING LAND MARKETS IN AGLINK-COSIMO

1. INTRODUCTION

1. An understanding of land use is essential for shedding light on a range of important policy issues. Firstly, food availability outcomes depend on interactions between land use (expansion), yields (including ex- and intensification), as well as economic drivers. Secondly, on-going land use changes, such as conversion of tropical forest to agricultural land, will impact on climate change (e.g. Harvey et al 2011). Thirdly, the impacts of policy instruments such as the decoupled payments under the EU Common Agricultural Policy, the Agricultural Risk Coverage or Price risk coverage instruments of the US Farm Bill or the biofuel promoting policies implemented around the globe will depend on how they affect land use. The Aglink-Cosimo model has so far only limited capability to analyse these issues given that the product coverage does not account for a country’s complete land balance and neither land resource restrictions nor competition of arable land with other land uses as pasture, forest or other land are implemented.

Objective

2. The major objective of this paper is to obtain a more complete representation of land in Aglink-Cosimo. This should have multiple pay-offs in future model applications in terms of both medium and long term policy issues that can be examined like effects of Indirect Land Use Changes (ILUC) on climate change, long term food security issues (in the sense of the availability of food supplies), the effects of biofuel policies as well as land based policies, etc. As land use representation will become a permanent feature of the model land use questions and outcomes can be explicitly addressed in any future model application.

Background

3. The approach is informed by a range of recent efforts in the field of (agro-)economic modelling to better capture land use related issues. Prominent examples are the GTAP-AEZ (Lee et al. 2009) approach, the introduction of land supply curves in CGE models (van Meijl et al. 2006) as well as agricultural sector models like ESIM (Shutes et al. 2012) or CAPRI (Adenäuer and Britz 2012) that equilibrate with agricultural land demand. At the same time models like GLOBIOM (Havlik et al. 2014) or MAgPIE (Lotze-Campen et al. 2008) feature a quite high disaggregation of land at a global scale. Given those developments the natural extension for Aglink-Cosimo is the implementation of a closed land balance.
Application

4. The functionality of the implemented approach will be examined via the analysis of policy scenarios that are likely to have a substantial impact on land use. One such scenario is the impacts of biofuel policy reforms (see TAD/CA/APM/WP(2015)28). Further potential applications include the analysis of land-based payments in the CAP and associated greening effects of its recent reform. The model could also be used to investigate the market implications of deeper structural changes such as land use change in Brazil or the effects of multi-cropping in China.

Structure of the paper

5. The content of this paper is as follows: Section 2 contains a review of existing land use modelling approaches; Section 3 contains the proposed approach for modelling land use in Aglink-Cosimo. Section 4 discusses data needs and availability. Section 5 proposes next steps and timelines.

Requests for technical feedback from capitals

6. We welcome expert feedback on the below proposed method for incorporating a land use representation into the Aglink-Cosimo model as described in section 2 and Annex A1 because this is an important model extension and has consequences for the further analysis.

7. We also welcome feedback on the country-specific estimates of land use, as presented in section 4 and Annex A2. The proposed model extensions require an extension of the database. FAOSTAT features a comprehensive land use database. However, the link between harvested areas used in the model and the crop land category is not straightforward because the latter counts multi-cropping as an effective increase in land area. National data on the level of multi cropping (per crop) would be of great help in supplementing the FAOSTAT data.

8. Since we would like to take this opportunity to review the land allocation elasticities in the Aglink module, any recent studies that report robust estimates would be of a great help.

2. REVIEW OF EXISTING LAND USE MODELLING APPROACHES

9. In this section, several possible approaches that reflect land constraints in a modelling system like Aglink-Cosimo are briefly compared to the current specification. The first requirement of a proper land allocation system is the ability to reflect a land constraint explicitly, while the second requirement is the ability to incorporate substitution between arable lands, pastures forest and other land categories. This section focusses on the first issue while the latter is addressed in section 3.

10. Six approaches have been reviewed in Annex A1 and the results are summarised below.
The current approach:

11. Agricultural harvested areas within the Aglink-Cosimo model are in most cases represented by functions responding to an expected return per hectare (including possible subsidies) as well as a correction for expected production costs for the crops in the current model version (compare equation 13 in the model documentation, OECD 2015). To facilitate further reading those elements driving the area response (prices, subsidies and costs) are defined as production incentives in this document. The elasticities driving those equations are chosen such that the harvested area system is homogeneous of a degree greater than zero meaning that the same relative shift in prices in all crop production activities will extend the total harvested area of the crops represented in the model. This makes perfect sense especially since not all crops are covered in the model. This representation does, however, not allow for analysis of scenarios targeting at changing the area constraint that naturally exists in agriculture. To allow for this, alternative solutions need to be found.

The EU-module approach of Aglink

12. In contrast to the standard specification, harvested areas are here represented by area share equations. Those area shares only react on own production incentives and those of the major crop in the EU (wheat). The harvested area of this cross product is calculated residually. On the one hand this method allows the reflection of the agricultural land constraint but on the other hand, having only one cross product in the equation means that the wheat areas substitute with all other crop areas, but the latter only substitute with wheat. Furthermore the residually calculation of the wheat areas bears the risk that this residuum turns negative. The EU-module approach is therefore not the best solution. The lack of substitutability between certain crops in the EU-module specification could be overcome with a simple extension: Rather than using one single crop as a benchmark, one could use a weighted average of all production incentives. Nevertheless, the area of one single product would still have to be calculated residually and there is no guarantee that this residuum has the desired global curvature, hence this approach is thought unsuitable to be transferred to the entire model.

Positive Mathematical Programming approach

13. Nonlinear programming models as e.g. CAPRI (Britz et al, 2004) use a quadratic cost term (quadratic in land allocation) to eliminate the over-specification problem typically existent in linear programming. This so called Positive Mathematical Programming (PMP) method could also be applied to equilibrium models by deriving the first order conditions of the maximisation problem. However, since the primal model is only quadratic in land allocations, the first order conditions defining the area allocation are linear and thus their second derivatives are zero and not below zero as desired. Therefore, and because crops do not even leave the rotation at zero profits, the PMP approach seems to be insufficient to be transferred to Aglink-Cosimo.

Constant Elasticity of Transformation approach

14. One of the most popular approaches to reflect the land allocation decisions in CGE and PE models (GTAP, ENVLINKAGES, PEM, DEVPEM) is the Constant Elasticity of Transformation (CET) approach.
Typically the land allocation problem is here nested into certain nodes and at each node a single substitution elasticity drives the allocation shares of each crop that is member of the node depending on their relative price development. Although this method has proven to be a good compromise between flexibility and a simplicity, it has one major drawback: The CET functional form does not preserve physical homogeneity of land, meaning that the sum of land across uses does not necessarily add up to the aggregate land total. Though it is possible to calibrate the system to a point where physical homogeneity prevails, as soon as the allocation moves away from this point, the sum over all uses of land will be smaller than the total available land at each node. Due to this feature the CET specification is also rejected.

**Adjusted CET approach**

15. Recently an adjusted CET approach was introduced in the ENVLINKAGES model which preserves the land identity. In contrast with the CET approach, where the underlying objective function is linear, but the land constraint is nonlinear, the latter is the standard land constraint in this case, but the objective function contains now a CET specification and the underlying problem is interpreted as utility maximisation. The first order conditions of this system are very similar to the standard CET case, only the price aggregator function differs slightly. In fact the solution of this system can be obtained by using the standard CET approach and apply a linear (across all members of a node) scaling factor. This system has almost all properties defined above. The only weak point regards flexibility. As each node has at least two members, even a complete nesting tree will only offer n-1 parameters to calibrate to n given own price elasticities meaning that a perfect fit for all elasticities cannot be achieved. This alone would be no reason to reject this approach, however, all cross price effects are implicit to the chosen substitution parameters. It is an empirical question if there is a need to calibrate the system to cross price elasticities, especially since literature lacks robust estimates. However, some examples exist where it might be necessary to set a certain cross price effect to zero. One example is that sugar beet and sugar cane areas in the USA are located in completely different regions. Therefore, direct substitutability should not exist.

**The GCAM approach**

16. A comparable method is implemented in the Agriculture and Land Use (AgLu) component of the Global Change Assessment Model (GCAM) developed by the Pacific Northwest National Laboratory (PNNL) for the US-Department of Energy (Sands et al, 2003). Similar to models using the CET approach, a nested structure is chosen with different levels of substitution assumed at the different nodes. Area shares are defined by the relation $IP_c^p / \sum_c IP_c^p$ (with IP being the production incentive) which add up to 1 by definition and they choose a similar price aggregation as in the adjusted CET case. The properties of this system are quite similar to those of the adjusted CET approach, but the theoretical foundation is stronger in the CET case.

17. To summarize this review, none of the examined approaches seems to cover the entire range of desired properties. One could now either waive one of the desired properties and choose one of the above approaches – in which case the adjusted CET approach would be the best choice – or design a new system. Given that calibration flexibility is deemed important for Aglink-Cosimo, a simple but flexible approach is proposed below, which appears to have the properties defined above.
3. A LAND ALLOCATION SYSTEM FOR AGLINK-COSIMO

18. The proposed approach combines several features of those presented above, but with a small extension. From the modified area share approach the assumption that the land use share planted for crop c \((LU_{..shr})\) depends on its own production incentive relative to an average one is adopted. To avoid one crop allocation having to be calculated residually the GCAM model approach to specify area shares based on

\[
\pi_c = \max \left[ 0, \alpha_c + \beta_c \log \left( \frac{IP_c}{IP_{c,AV}} \right) \right] R_c
\]

\[LU_{..shr} = \frac{\pi_c}{\sum_c \pi_c}\]

\[IP_{c,AV} = \sum_{i \neq c} y_{c,i} IP_i\]

\[LU_c = LU_{..shr} \cdot A_{modl},\]

\[AH_c = LU_c \cdot CRPI_c\]

the share of single crop profits \((\pi_c)\) in total profits \((\sum_c \pi_c)\) is adopted. As an extension, the average production incentive \((IP_{c,AV})\) used to denominate the own crop production incentive \((IP_c)\) is now product specific and calculated as an aggregate of only cross product prices with fixed weights\((y_{c,i})\). The latter can be chosen to influence cross price behaviour. Additionally, a linkage between land use shares, effective land use of a crop \((LU)\) and total available land for crops modelled \((A_{modl})\) in absolute terms is needed as well as linkage between land use and harvested areas \((AH)\). The latter is done by multiplying an index \((CRPI)\) to the land use variable which covers multi cropping but also growing failure rates.

19. \(\beta\) and \(\alpha\) are parameters of the function \(\pi\) which can be interpreted as the relative profit rate per crop, which as long as \(\beta\) is positive, increases as own the own production incentive increases and decreases as the average of alternative product or cross incentive increases. A calibration factor \(R\) is added to this equation in order to allow for flexible calibration to area shares.

20. One additional difference between this approach and the previous ones is that land allocation to crops can now leave the rotation when production incentives are low but still positive - which is not implausible at all. Given the larger number of parameters, a better calibration to given elasticities compared to the other reviewed approaches is achieved as illustrated in annex A1.

**Substitution with other land categories**

Equation system 1 can be implemented in the model, but the total area of crops represented in the model \((A_{modl})\) is not a constant given the possibilities to substitute with other land use categories. The question is
left open, how this substitution could be determined. Generally land devoted to crops in the model should increase if the average profit of those crops increases and vice versa. But where does this area come from (or go to)? Relevant land supplying categories are other crops, pastures, forest and other areas (the residual to a country’s total area). A simple representation of the area competition would be a system of land demand functions depending on the average profit in model crops for those categories as plotted in figure 1.

Figure 1. Land demand functions for land categories

21. The demand for each land category is a function with negative slope. This slope determines the substitutability amongst model crops. The implicit net supply function of the four land categories is also shown which is naturally increasing in average profits. In reality the demand for a certain land category depends not only on the profitability of those crops modelled (which approximate the land rent), but also on the profitability of its own use as well as conversion costs. The latter could however be captured in the choice of the \( \phi \) parameter. A \( \phi \) parameter set to zero would imply no substitutability which would increase with higher values for \( \phi \). A complete land market added to equation system 1 could therefore be:

\[
TL = \sum_l A_l
\]

\[
A_{l\neq mod} = A_{l, bas} \left( \phi \ln \left( \frac{IP_{mod, AV, bas}}{IP_{mod, AV}} \cdot \frac{IP_{LAV}}{IP_{LAV, bas}} \right) \right)
\]

\[
IP_{mod, AV} = \sum_c AP_{..} shr_{c, bas} IP_c
\]
22. Where TL denotes the total available land area of a country, A is the area allocated to the five land categories l of which modl denotes the Aglink-Cosimo crop area aggregate. The incentive for all categories but those in the model will most likely be an exogenous variable. An exemption will be pastures. Here the incentive price will be linked to average returns from ruminant products (beef, sheep meat and milk products) included in the model.

23. A major challenge will be to specify the response parameters φ in this system as they determine the degree of competition between the different land use categories. One might try and estimate a simple land use demand system for each country in which land areas (for arable land, forestry, pasture and other uses) are a functions of their long run land use returns. This might (assuming data are available to do it) enable the substitutability at the margin between land types to be determined. If such estimations fail, it is still possible to borrow parameters from other models like GTAP.

4. DATA NEEDS AND AVAILABILITY

24. In order to implement equation systems 1 and 2, a statistical database is needed. FAOSTAT offers a global land use database available in their inputs domain. Figure 2 gives an overview on major land categories in that database and the link to the model integration.

![Land categories in FAOSTAT](image)

25. The top three categories (6600, 6601 and 6680) are basically fixed. Competition arises therefore only among land area. One can find the categories necessary to set up a system as proposed in equation 2.
However, the areas of the lowest level have to be calculated somehow. On first sight it seems straightforward to simply sum up the crop allocations of the model to obtain the model crop area and then calculate other crops residually from the FAOSTAT crop area.

**The issue of multi cropping**

26. However the issue of multi cropping has to be born in mind: In absence of multi cropping harvested areas are equal to the land use of a crop, but if it is present, land use requirements of those crops are lower. That means, if multi cropping is an important practice for any of the model crops, the combined land use of model crops (model crop area) is lower that the simple sum over harvested areas and thus the other crop land use calculated as crop area minus model crop area would be underestimated and could theoretically even become negative when multi cropping was an important practice.

27. A first idea to evaluate of the importance of multi cropping in the countries of the Aglink component is to calculate the ratio of all harvested areas in the FAOSTAT database and the crop area variable. Figure 3 gives the result of the calculation of an average cropping intensity for 2012. Unfortunately, with the exemption of China, the cropping intensity is below 1 meaning that there are still areas categorised as crop areas but not covered with those crops recorded in FAOSTAT. FAOSTAT does not include fodder crops or areas that did not get harvested due to frost, flood or drought events. Furthermore abandoned crop land might be recorded in land statistics. Having this in mind it does not seem to be unrealistic that countries with a higher production failure risk are found on the right hand side of figure 3, while those where multi cropping is likely to play a relevant role are located to the left.

**Figure 3. Cropping intensities in Aglink countries**

28. However, even if it is not the first priority to model cropping intensities endogenously, it is essential to have a database that reflects them ex-post in order to properly calculate the other crop area category and to have an estimate that translates harvested areas into demand for arable land. So far only one study is available that calculates such cropping indices globally per crop (Siebert et al, 2010) based on the
Micra2000 dataset, a database with global monthly irrigated and rainfed crop areas around the year 2000. This method is used as the standard calculation but if detailed country information can be found, it can be overwritten. The cropping index is here defined on the relation between the maximum growing time of a crop and the time a crop is present per year. Since the dataset is based on an average around the year 2000, recent developments of increasing relevance of multi cropping will not be captured.

29. Having the model crop area and the other crop area calculated, an overview of the land use situation in the countries featured endogenously in the Aglink component is given in Annex A2 showing also historical developments over the past 2 decades.

30. This illustration gives a good overview on the land use situation in the analysed countries; it does however give only limited information on the quantity of land that is suitable for cropping activities. Especially the definition of the other land category has to be examined further as its substitutability depends on what is included. If that category includes urban land and all other land mountains, etc which will never be useful for agriculture except at immense cost of reclamation for agriculture, then surely the total supply of land which might go into agriculture, forest or pasture is very limited, and land use reallocation will take place within the other uses only. If on the other hand, other land is a category which although not currently under cultivation, pasture or forest, might still be convertible for some or all of those uses, then the net supply function will have a positive slope relative to use profitability.

5. NEXT STEPS

31. Technically the proposed system has been implemented for the US module of Aglink so far. In the next step it should be taken over to all countries covered. There will be opportunities for consultation at the Commodity Group meeting, and later at the Aglink-Cosimo Users’ Group meeting. Furthermore a presentation of the methodology at the World Outlook Conference in 2016 is foreseen. The final specification will be added to the Aglink-Cosimo model documentation by November 2016.
REFERENCES


ANNEX A1: DETAILED COMPARISON OF LAND USE MODELLING APPROACHES

32. By using a simple example where a region’s decision on the allocation of 5 crops (wheat, maize, soybeans, rape seed and sugar cane) to available land several existent land allocation methodologies are reviewed. For now it is assumed that harvested area is equal to the land use of a crop so that multi cropping is disregarded. This issue has been examined in section 3. All presented approaches have in common that the decision on land allocation is detached from the actual intensity decision. Land allocation is planned with respect to (wrt.) expectations for prices, yields and costs in a first step, while the intensity decision is a second step and represented by yield response functions which are not discussed here. The focus is only on the land allocation decision of farmers.

The Aglink-Cosimo template for harvested area

33. As a starting point the current template specification of the Aglink-Cosimo model is presented which features response equations of harvested areas to production incentives which have the general double log type:

\[
\log(AH_{r,c,t}) = \alpha + \beta_1 \log(AH_{r,c,(t-1)}) + \sum_{c1(crop)} \beta_{c1} \log \left( \frac{RH_{r,c,(t-1)} + EPA_{r,c,(t-1)}}{y_c \times CPCI_{r,c,(t-1)} + (1 - y_c) \times CPCI_{r,c,t}} \right) + \beta_2 \times TRD
\]

34. Where AH = harvested area, TRD = trend variable, R= annual calibration factor, RH = market returns per hectare, EPA = subsidies affecting area, CPCI = cost of production index (2008 = 1), \( y_c \) = share of production cost occurring in the previous marketing year and \( \alpha \) and \( \beta \) are parameters while \( r \) denotes regions, \( c \) crops and \( t \) years. The term in brackets can be interpreted as the expected values of the production incentive for each crop that experiences increases in price and subsidies and decreases in costs. Since it will appear in many of the following equations it is referred as incentive price or production incentive in this document.

35. The applied elasticities \( \beta_{c1} \) were once estimated but not updated regularly, calling into question whether their empirical base is still valid. Furthermore the nature of these equations does not enable land restrictions to be reflected as a total land variable does not exist. Given that the model only includes major crops, this was argued to be less important. Additional land could still come from other crops without reaching land restrictions. However, it limits the capability of the model to examine land resource constraint scenarios.

36. Following the five crop example, each crop-specific harvested area function of the above type is calibrated assuming the following elasticities (which are taken from US module) and base area allocation (chosen arbitrarily, adding up to 100):
Table 1. Input data for five crop example

<table>
<thead>
<tr>
<th>Area Elasticities</th>
<th>Base Areas (ha)</th>
<th>Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>-0.300</td>
<td>-0.028</td>
</tr>
<tr>
<td>Wheat</td>
<td>-0.044</td>
<td>0.180</td>
</tr>
<tr>
<td>Soybeans</td>
<td>-0.199</td>
<td>-0.038</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>-0.060</td>
<td>-0.081</td>
</tr>
<tr>
<td>Rape seed</td>
<td>-0.030</td>
<td>-0.100</td>
</tr>
</tbody>
</table>

37. For the following experiments it is suitable to choose the incentive prices to equal 1 for all crops in the calibration point. The annual calibration factor \( R \) is fixed at 1 since the time dimension is disregarded for now. To illustrate the functional form of equation 3 six experiments are designed. In each of the first five experiments the incentive price for one crop is gradually increased from 0 to 2 (0% and 100% of the calibration point). In the sixth simulation the incentive prices for all crops are gradually increased at the same time. The results of the first five experiments are illustrated in figure 4 and those of the last experiment in figure 5.

38. Concentrating on the own price effects in the five experiments of figure 4, the functional form does reveal three desirable properties. (1), land allocation to a crop is increasing in own price, the marginal area change decreases and allocation to a crop disappears if its incentive price becomes zero. Cross-price effects also look plausible as long as the price decrease of the respective crop is not higher than about 80%. If it is higher the functional form leads to strong increasing land allocations to all other crops which are not very plausible. However, it is quite unlikely that any simulation carried out with Aglink-Cosimo will lead to such strong decreasing incentive prices so that this feature could be neglected so far.

39. The illustration also reveals that the total area occupied by the five crops is increasing one of the prices is increased, at least when concentrating on the range above 20% of the base price. How strong this increase is (or even a decrease appears) is a matter of the initial elasticities and the initial crop shares. The degree of homogeneity of the system can be illustrated in figure 5, where all crop incentives are moved at the same time. All crop areas are increasing and total land is also increasing, in this case with an elasticity of about 0.1 with respect to average incentive prices. This implies that other land categories must supply additional land to those crops with the same elasticity and the total land curve could be interpreted as land
supply curve to our five crops and in the case of Aglink-Cosimo to those crops explicitly modelled. For conducting land resource pressure scenarios, it should be possible to alter the slope or the level of this curve, wherefore a new approach is needed. Possible alternatives that explicitly reflect a land constraint are discussed below. It is therefore assumed that the total area in the five crop example is fixed at 100 ha wherefore the sixth experiment is not carried out for the subsequent approaches.

Figure 4. Price experiments with the current Aglink-Cosimo specification

40. As already applied to the example above, the following desired properties are examined for all reviewed approaches:

- Global curvature: The crop area should strictly increase if its production incentive increases ceteris paribus. The same is true for cross reactions with the opposite sign: If two crops are not complementary, the area of one crop should strictly decrease if the incentive of the other crop increases. Furthermore it becomes more difficult to extend the area of a crop if that crop already takes a large share of the rotation as rotational restrictions may become binding and the extension might take place on less suitable soil. Therefore the second derivative of crop areas with respect to their own production incentive should be negative.

- Corner solutions: If the production incentive of a crop were reduced to zero it should leave the crop rotation.
Manageability: The system should be flexible enough to retain the current behaviour of the model within certain limits, but as simple as possible. It further needs to be easy to be calibrated to any external (consistent) set of area shares and elasticity estimates.

Figure 5. Price experiments with the current Aglink-Cosimo specification (2)

The Aglink-EU-module approach for harvested area shares

41. In the EU module of the Aglink component a different approach is chosen. Additional crops or crop aggregates are introduced such that arable- and grassland is completely covered. Harvested areas are represented by area share equations, distributing a fixed agricultural area to agricultural land uses, pastures being set exogenously. A further difference to the Aglink-Cosimo template is the specification of cross effects since the area share of a certain crop only depends on its own incentive price relative to that of a reference crop. This reference crop is chosen to be soft wheat as it is the dominating crop in the EU and the area share of soft wheat can be calculated residually. For better readability, the subscripts r and t are skipped in the following keeping in mind that all equations would exist also for a regional and time dimension. Trend and calibration coefficients are also disregarded for now and maize is used as benchmark crop as it has the highest share in the 5 crop example. This leads to the following equations:

\[
\log(AH_{\text{shr}_c}) = \alpha_c + \beta_c \log \left( \frac{IP_c}{IP_{MA}} \right)
\]

\[
(AH_{\text{shr}_{MA}}) = 1 - \sum_{c \neq MA} AH_{\text{shr}_c}
\]

\[
AH_c = AH_{\text{shr}_c} \times ARAB
\]
42. with IP denoting the production incentive equal to the term in brackets in equation 3, MA denoting maize and ARAB the available Arable land. Applying this equation system to the 5 crop experiment example while assuming that those 5 crops cover the complete arable land and choosing maize as the reference crop with the highest cropping share leads to figure 6:

Figure 6. Price experiments with Aglink-EU-Module type area share equations

43. The EU-Module specification reveals two major disadvantages: As visible in the maize price experiment, if the maize price is reduced below 40%, the system can no longer be solved because the residually calculated area share of maize tries to become negative, which conflicts with the non-negativity restriction of land. Again one might argue that such a strong reduction in expected maize prices without the other crops prices also adjusting is implausible so that this range of the equation system is irrelevant. However there is the second disadvantage of the system which is that though all crops react on the maize price, maize is the only cross-product responding to changes in incentive prices of other products. This behaviour is certainly not desirable. A slight modification of this approach could be the:

**Modified approach for harvested area shares**

44. Rather than using the incentive price of the crop with the highest cropping share as a reference, one could use an aggregate price index of all crops. This would turn equation system 4 into system 5, where such a price index is calculated as the weighted average of single crop incentive prices using the cropping shares at the calibration point (bas) as weights. The reason for using those shares and not the actual simulation shares is that the price index can potentially decrease if one of the single crop prices increases
in those cases where crops with lower prices gain shares. This specification heals the two problems stated above, as visible in figure 7. All crops react more or less on all prices and the maize area is not attempting to become negative. However, even if the maize price is zero, the cropping share remains at about 20%.
Additionally one can observe in the wheat price experiments that the residual maize area is first decreasing but then increasing again after a certain point because the soy bean area is decreasing stronger than the wheat area is increasing. This could be avoided by choosing a different set of parameters, but steering cross effects with the own price elasticity only seems to be a strong restriction in this case. However the specification of the EU module had also the goal to reduce parameters in the system, which of course reduces flexibility to some extent.

Looking out for alternative solutions, it might be worthwhile to review how other models that try to represent the agricultural sector have implemented land use. Many approaches found here are based on
microeconomic theory having in common, that some profit or utility function is maximised with respect to a land constraint. Those profit or utility functions are characterised by decreasing returns to single crop allocations which is a necessary condition for a system to have a global optimum. A prominent approach in non-linear programming models like CAPRI or FSSIM is the Positive Mathematical Programming (PMP) approach which ensures calibration to any observation and decreasing returns or increasing costs to increasing land allocation. While PMP is generally widely applied in programming models, the idea of specifying a regional profit function, concave in land allocations, can also be applied to equilibrium models:

**Profit Maximisation with quadratic cost function**

47. In the original PMP approach (Howitt, 1995) it was proposed to add to the explicit specified elements of the gross margin of a crop definition in a linear programming model a quadratic cost function so that farmers optimisation problem would lead to:

\[
\begin{align*}
\max \pi(AH_c) &= \sum_c IP_c AH_c - (\alpha_c AH_c + 0.5 \beta_c AH_c^2) \\
\text{s.t.} \quad & \sum_c AH_c = L [\lambda] \\
& AH_c \geq 0 [\gamma_c] 
\end{align*}
\]

(6)

48. \(L\) denotes the total available land that can be allocated to the \(c\) crops. The incentive price \(IP\) is not equal to an explicit specified gross margin as used in programming models but it can be used as proxy without losing the properties of the approach. To be applicable to an equilibrium model, the lagrangian dual formulation of first order conditions of this primal model is necessary. Those can be obtained by substituting the restrictions into the objective function:

\[
\begin{align*}
\max \pi(AH_c) &= \sum_c IP_c AH_c - (\alpha_c AH_c + 0.5 \beta_c AH_c^2) + \lambda \left( L - \sum_c AH_c \right) + \gamma_c AH_c 
\end{align*}
\]

(7)

and then taking the first derivatives wrt. to all crop allocations and shadow prices \(\lambda\) (land rent) and \(\gamma\) (shadow price of the non-negativity restriction) which then yields:
The last condition (so called complementary slackness) is needed to ensure that either \( \gamma \) is zero, or the respective land allocation as the non-negativity restriction is an inequality. Applying this system to the 5 crop example, using the initial elasticity matrix to determine the \( \beta \) parameters leads to figure 8, illustrating the properties of this system. Compared to the previous specifications one can see that the system is quite linear and even at prices being zero, a crop will still be found in the optimal solution rendering this approach not very attractive.

Figure 8. Price experiments with the PMP approach

\[
0 = IP_c - (\alpha_c + \beta_c AH_c) - \lambda + \gamma_c \\
s.t. \sum_c AH_c = L [\lambda] \\
AH_c \geq 0 [\gamma_c] \\
AH_c \gamma_c = 0
\] (8)

49. A further prominent approach worth to be looked at is the Constant Elasticity of Transformation (CET) landmarked approach widely used in general equilibrium models.
CET land markets

51. Prominent models using this approach are GTAP and its children as well as the OECDs PEM and DEVPEM models or ENV-LINKAGES. Comparable to the previous specification, it starts form a profit maximisation approach. However the land constraint is a non-linear CET function:

\[
\text{Max } \pi(AH_c) = \sum_c IP_c AH_c \\
\text{s.t. } \sum_c [g_c AH_c]^{\frac{1}{\delta}} = L
\]  

(9)

The dual formulation of this system leads to a set of land demand and average price equations:

\[
AH_c = \gamma_c L \left[ \frac{IP_c}{IP_{AV}} \right]^\rho \\
IP_{AV} = \left[ \sum_c \gamma_c IP_c \right]^{\frac{1}{1+\rho}}
\]  

(10)

52. where \( IP_{AV} \) represents the (CET) price of aggregate land and \( \gamma \) are called the (dual) CET share parameters and \( \rho \) is called transformation elasticity and \( \rho=1/(1-\delta) \) and \( \gamma_i=g_i^\rho \). There is one major drawback of this approach namely that it does not preserve physical homogeneity of land, meaning that the sum of land across uses does not generally add up to the aggregate land total. This problem is visualised in figure 9 where again the 5 crop example was applied. Here a two-level nesting was choses: On the upper level, cereals, oilseeds and sugarcane substitute against each other and on the second one there is substitution within the cereals and oilseeds nests.
Figure 9. Price experiments with CET land nests

53. A feature of this approach is that the sign of cross price effect may change as visible when looking at the wheat area response in the maize experiments. Even though the effect is small, one can see that wheat area is slightly increasing in the left half of the graph and decreasing in the right one. Additionally the cross price effect of rape area to the soybean price is positive, although the calibration procedure tries to minimize the differences to the original elasticity matrix. Of course the number of free parameters in the system is too low to achieve exact calibration, but it would be desirable to at least preserve the right signs. This can be achieved by imposing certain relations between the substitution elasticity of lower and upper nests to ensure that crops are substitutes. Additional restrictions will however decrease the fit to original elasticities.

54. As noted above, it becomes further visible that the sum over physical crop areas is only equal to the 100 available hectares in the calibration point (100%). Moving from there in any direction reduces the total and the difference becomes higher the farer away one moves away from it. If the ρ parameters where higher this effect would be even stronger. To circumvent this problem, it was often proposed to apply a common scaling factor to all crop areas such that total land is fitted, however so far there was no theory justifying such a factor until recently an alternative CET approach was introduced in the ENV-LINKAGES model.

Adjusted CET land market

55. Here, different to the standard CET approach in equation system 9, the land constraint is linear and the CET function appears in the objective as utility function to be maximised.
leading to the dual system:

\[
\begin{align*}
\text{Max } U(AH_c) &= \left[g_cAH_c^\sigma\right]^{\frac{1}{\delta}} \\
\text{s. t. } \sum_c AH_c &= L
\end{align*}
\]


(11)

56. Note that the differences between systems 12 and 10 are only the exponents of the price aggregation equation. However, the linkage to the primal parameters is also different: \(\rho = \frac{\delta}{(\delta - 1)}\) and \(\gamma = g_1^{1/\delta}\). Albeit, it can be shown that for choosing identical values for \(\gamma\) and \(\rho\), the resulting area shares from system 12 can be obtained by multiplying the resulting shares of system 10 by the constant factor \(\frac{I_P A V}{I_P A V^2} \frac{1}{\rho}\). The properties of this system in the 5 crops example are shown in figure 10. As intended, total land is now constant but the cross price issue remains. The latter might again be possible to be overcome by imposing restrictions on the cross price elasticities during calibration.

57. A comparable method is implemented in the Agriculture and Land Use (AgLu) component of the Global Change Assessment Model (GCAM) developed by the Pacific Northwest National Laboratory (PNNL) for the US-Department of Energy (Sands et al, 2003). Similar as in models using the CET approach, a nested structure is chosen with different levels of substitution assumed at the different nodes. Area shares are defined by the relation \(\frac{I_P^\rho}{\sum_c I_P^\rho}\) (with IP being the production incentive) which add up to 1 by definition and they choose a similar price aggregation as in the adjusted CET case. The properties of this system are quite similar to those of the adjusted CET approach, but the theoretical foundation is stronger in the CET case.

58. Summarizing the so far examined land allocation systems it occurs that none of them has all the properties desirable for the Aglink-Cosimo model. Especially the steering of cross price effects might be too limited as it is sometimes necessary to set the cross price effect of one crop to the price of another one. Therefore a simple but flexible land allocation approach is developed below.
A simple flexible landallocation (SFL) approach

59. The approach presented here combines several features of those above with a small extension, lacking, however, a micro theory based foundation. From the modified harvested area share approach the assumption that the share of a certain crop depends on its own price relative to an average price is taken over. To avoid that one crop allocation has to be calculated residually the idea from the GCAM model to specify area shares from the share of single crop profits in total profits is adopted. As an extension, the average incentive price ($IP_{c,AV}$) used to denominate the own crop price ($IP_c$) is now product specific and calculated as an aggregate of only cross product prices with fixed weights($\gamma_{c,i}$) which can be chosen to influence cross price behaviour.

\[
\pi_c = \max \left[ 0, \alpha_c + \beta_c \log \left( \frac{IP_c}{IP_{c,AV}} \right) \right]
\]

\[
AH_{shr_c} = \frac{\pi_c}{\sum_c \pi_c}
\]

\[
IP_{c,AV} = \sum_{i \neq c} \gamma_{c,i} IP_i
\]
60. $\pi_c$ can be interpreted as simple crop specific profit function with decreasing returns to increasing own prices. The max-operator is necessary to avoid the function and thus area shares to become negative. One can now again apply the 5 crop example to this system and obtain the following picture:

**Figure 11.** Price experiments with the simple and flexible land allocation approach

61. Compared to the adjusted CET approach, the signs of cross price effects do not change over the examined range, with the exception of the sugarcane experiment in the range where sugar cane leaves the rotation because there, changing sugarcane prices no longer impact on the sugarcane area (through the max operator) but cross products still react. Driving the sugar cane price down to zero in a range where sugar cane is no longer cropped implies that the denominator in the area share equations has only increasing elements and no decreasing ones anymore, scaling all cross product areas down, which can lead to positive cross price effects in this case.

62. The capability of the presented approaches in terms of elasticity fit is illustrated in figure 12, where the sum of squared errors between the original elasticity matrix and the obtained elasticities for the presented approaches is given distinguished between fits for own and for cross effects. Since the absolute value of the sum of squared errors is meaningless, no values are plotted on the x-axis. One can see that the specification as applied in the EU module has by far the worst fit, since some cross effects are fixed to zero by design and the maize own price elasticity is implicitly given by those of the other products. The best fit can be obtained with the simple and flexible approach proposed in equation system 1 especially concerning own price effects so that next to the almost global “right” curvature in this system, another criterion appears in favour of this approach. It has however the highest number of parameters to be specified. If number of parameters is a more relevant criterion, the adjusted CET approach appears to be best suited.
Figure 12. Elasticity fit of area allocation approaches

- Simple & flexible
- Adjusted share equations
- Adjusted CET
- CET
- GCAM
- PMP style
- EU share equations

[Diagram showing elasticity fit for each approach]
ANNEX A2: LAND USE DATA IN AGLINK COUNTRIES

63. In Argentina 274 Mha are available and largely covered by pastures and other land. One can observe a strongly increasing trend for model crops. At the same time forest land decreased continuously.

Figure 13. Land use in Argentina

Figure 14. Land use in Australia

64. The country area of Australia amounts to 768 Mha less than half of it being pastures. The latter tends to decrease over time and the same is true for forests in the previous decade. Other land is strongly
increasing between 2000 and 2010, however it cannot be excluded that this is a statistical error. There is furthermore a slightly increasing trend on modelled crops, while other crops are decreasing.

65. Brazil’s land area amounts to 836 Mha and Forest take by far the largest land cover, followed by pastures. During the past decades forest areas were decreasing while crop areas increased especially in the previous decade.

Figure 15. Land use in Brazil

Figure 16. Land use in Canada
66. In Canada, the situation has been even less dynamic in the past 20 years. 909 Mha of available land area is to a large extent covered by forest and other land. Agricultural land takes only a very small share (about 7%). There has been a small reduction in crop areas, extending other land in the past 10 years, a strong conversion rate between the 5 land categories seems however not to exist.

67. The available area in China adds up to 942 Mha with pasture being the dominating land use type. A strong increase can be observed for forest areas probably induced by the Three North Shelterbelt Project, one of the world’s largest tree-planting projects. Since 1978, 66 billion trees have been planted by Chinese citizens. By the end of the project in 2050 it is intended to cover large areas along the edges of China’s northern deserts, and increase the world’s forest cover by more than 10%. Other land is trending downwards, while the crops modelled in Aglink are slightly increasing.

Figure 17. Land use in China

68. Land use statistics in FAOSTAT for the countries of the European Union start only in 1993. Total 425 Mha are covered by 50% with agricultural areas while forests still take the highest share of the 5 single categories (about 35%) with an increasing tendency. Pastures were stagnating between 1993 and 2000 and slightly decreasing thereafter. As mentioned before, the EU representation in Aglink features a complete land balance for agricultural areas so that all crops are somehow modelled or at least an exogenous part in the land balance. Model crops refer here, as in any other case, only to those for which the model has market clearing equations. The observed increases in crop areas and forests were mainly fed by reductions in other land in the past.
69. In Japan 30 Mha are available of which forest covers 25 Mha and pastures less than 500000 ha. Forests tend to increase over time and increasing other areas are fed by cropland.

70. Amounting to 10 Mha the land area of Korea is comparable low and above 6 Mha are covered by forest. There are hardly any pasture areas. But there are dynamics in all land categories. Rising demand for other land (probably through urbanisation) meets decreasing forest areas and areas of the modelled crops.
The total land area in Mexico amounts to 194 Mha, with large shares taken by forest and pasture. Forest areas show a declining trend and to lesser extent pasture as well. While the area of crops modelled is quite constant again other land and other crops are on increasing paths.

Mha of available land in New Zealand are largely covered by pasture and forest. The crops modelled in Aglink take a share below 1%. The sharp increase in other land during the last decade at the expense of pastures might again be a statistical problem.
In Russia the predomination land use category is forest covering 50% of the 1638 Mha total land surface. Another 36% are categorized as other land, while the agricultural land use types only account for 13% of the land balance. Still with about 220 Mha this is more than the entire land cover of Mexico. Net crop area was slightly decreasing over the past decades.

The situation in the United States is shown in figure 5. In total 916 Mha land area are available. The largest shares are covered by forest and pasture followed by other land. The dynamics in each land category are limited. There is an increasing trend in forest, pasture and other land areas facing almost constant areas of model crops and decreasing trends on other crops since 1990. Those trends might
partially resulting from the Conservation Reserve Program (CRP) that was originally introduced to counteract actual or potential erosion since the early days of the US-farm-bill.

Figure 24. Land use in the United States

75. The situation in Norway and Switzerland are not explicit shown given the exogenous nature of both country modules.