The effecto of different model specification on model outputs: The case of a computable gereral equilibrium (CGE) model

Abstract

Model outputs of different models such as computable general equilibrium (CGE) models differ between several models. Studies on plausible futures for agricultural production and food security came to deviating results even with matching assumptions on macroeconomic parameter choices and external drivers. Concluding this research, we regarded structural aspects of the modelling approaches in one computable general equilibrium (CGE) model which allows us to point on the effects of different model specifications. We show that not only the choice of sensitive parameters and model structures but also the effect of differences in reference runs need to be considered. When addressing price changes due to a policy shock, differences in land-use modelling, and choices of critical parameters are the main drivers of variations in price. Further up in the production chain, diverging results are mainly driven by the representation of by-products. Our results call for transparency on model assumptions and model limitations and careful consideration of model-based policy recommendations. Only with this information the applicability of certain modelling approaches for a particular policy question can be appropriately assessed.

1. Introduction

Simulation models of agricultural systems are tools to inform decision makers about possible future pathways of the agricultural sector to address land use change and food security. Global agricultural markets are determined by economic and institutional drivers and bio-physical conditions. Factors influencing the development of these markets include climate change and demographic changes as well as an increasing globalization of agriculture paired with an increasing divergence between regional supply and demand of biomass. In addition, agricultural production and agricultural markets are highly influenced by numerous political interventions, e.g. through subsidies for biofuel production or agricultural policies such as the Common Agricultural Policy of the European Union. Furthermore, in the medium- to long-run higher incomes may also alter lifestyles and consumption patterns. Such future pathways of socio-economic and environmental systems can only be assessed with scenarios. For this, numeric models are one important tool.

Recent studies of plausible long-term futures for agricultural production and their impact on agricultural markets and on food security have shown diverging results (von Lampe et al. 2014). This creates a challenge for decision makers who want to make use of scenario analyses to design policy strategies but are faced with a wide range of potential impacts presented by different modelling exercises (see e.g. OECD (2015)). The Agricultural Model Intercomparison and Improvement Project (AgMIP) compares model results of ten global economic models (six Computable General Equilibrium (CGE) models covering the whole economy and four partial equilibrium models focused on agriculture alone). Therefore, the modelling teams harmonized the assumptions on key drivers (GDP and population growth, exogenous parts of crop yields changes, energy prices, and production of biomass-based energy). Von Lampe et al. (2014) conclude that the harmonization of the assumptions and reporting has helped to narrow the spread of scenarios results, but major differences remain across the models. They suggest to perform controlled and straight-forward sensitivity experiments on both the supply and the demand side that would allow for the generation of comparable price elasticity matrices for area, yield, and final demand across agricultural products. Such sensitivity analysis were conducted by Nong2019 who tested the sensitivity of 3% or 5% saving rate and the substation elasticities between fossil and biobased outputs on the chemical output from bioeconomy, van der Mensbrugghe (2013) run the model with specification and parameters of the ENVISAGE model on agricultural productivity and land supply

We argue that the remaining large differences in the outputs of the scenario analysis are caused by 1) differences in representing the complex production and value chains of agricultural goods such as especially the multi-functionality of many agricultural raw materials and the multi-product aspect of many food-related activities, 2) differences in methods for modelling land use, 3) different choices of some critical parameters, and 4) substantial differences in model structures. This makes direct comparison seems to be almost impossible. We further argue that for understanding differences in model results it is therefore not sufficient to harmonize macroeconomic parameter choices and external drivers, instead structural aspects of the modelling approaches also need to be looked at as well. Their influence needs to be communicated in order to make the causes for the results of a particular policy analysis more transparent.

To illustrate this, we use the global CGE model DART-BIO (Dynamic Applied Regional Trade) to analyze with just one model the different approaches used in recent studies. In addition to previous studies, we analyze the linkages between livestock and biofuel production via joint production processes of their inputs. DART-BIO has not been part of the modelling comparison exercise by von Lampe et al. (2014). However, the model has been developed and modified in such a way to include many of the features tested to understand the causes of differences in the results of the 10 models applied in the comparison exercise. The use of only one model allows us to look directly at the effects of different assumptions concerning the model differences mentioned above. We implement these approaches by running several versions of DART-BIO with different formulations of the structure of production, land use modelling and parameter values.

The paper is structured as follows: after the introduction, we provide a literature overview on how land is integrated into CGE models and point out key aspects that need to be considered when modelling land use and land use change. In section 3, we introduce a new version of the DART model, named DART-BIO, which treats land as a heterogeneous production factor and includes a detailed representation of biofuels, its feedstocks and its by-products. The following section 4 introduces the way in which we compare the different model designs that are used in the literature. We identify several alternative model structures and parameter choices that we consider crucial. We then define a realistic policy scenario and an artificial testing scenario which we use to illustrate the impact of the different approaches on the scenarios. In section 5 we present the scenario results and discuss the influence and the importance of the different model and parameter choices on those results. The final section summarizes and concludes.

2. Land data and land use modelling in CGE models

Accounting for land heterogeneity is crucial in land use modelling, because land use decisions and planning imply that crop production requirements based on their biophysical limitations and potentials are appropriately taken into account in the CGE models.

2.1. Land use data in the GTAP database

With the introduction of Agro-Ecological Zones (AEZ) into the Global Trade Analysis Project (GTAP) database, the (former) homogenous land endowment in GTAP has been replaced by 18 types of land in each region. Each of the 18 AEZs is characterized by its particular climate, soil, and landform conditions which are basic for the supply of water, energy, nutrients and physical support to plants. The GTAP7 land use data has been updated to GTAP8 by Baldos and Hertel (2012).

2.2. Land use modelling in CGE models

Kretschmer and Peterson (2010) provide an overview on different approaches to model land use in CGE models. They explain that the simplest approach is to model land, as performed by Dixon et al. (2007) and Kretschmer et al. (2009), as a homogenous factor of production in the agricultural sector. However, this approach faces evident shortcomings that have been addressed in the literature. In fact, the natural heterogeneity of land is not taken into account, the capacity and potential for substituting between different types of land is limited, and endogenous mechanisms of land expansion/conversion cannot be included when applying this approach (see e.g. Hertel et al. 2010, Bouët et al. 2010, Al-Riffai et al. 2010).

The GTAP-AEZ database differentiates between three types of land that are devoted to different economic activities: cropland (crop production), pastureland (cattle raising) and managed forest (forestry). They are characterized by their economic values (land rents). The mobility of land from one of these land types to another economic use is commonly restricted by a nested constant elasticity of transformation (CET) function (see e.g. Banse et al. 2008, Hertel et al. 2010, Bouët et al. 2010, Al-Riffai et al. 2010, Laborde 2011, Laborde and Valin 2012).

Within each region (in the case of a single land endowment) or within each region and AEZ (in the case of GTAP-AEZ) the land endowment is allocated to different uses based on the changes in the relative land rents in these activities, leading to a substitution effect. In addition, the total land endowment might be extended by converting unmanaged land into farming land, leading to an expansion effect. Some models include expansion of agricultural and forestry activities into natural, so far unmanaged areas (cp. Banse et al. 2008). These unmanaged areas are not represented in the GTAP-database. In this case, by introducing a non-zero supply elasticity for land higher prices for managed land expand the endowment of managed land.

In addition, there are different assumptions about the land rent adjustments within cropland. Most models assign the land rent to a particular crop and include an elasticity of substitution with the effect that land use moves from one crop to the other according to their relative prices. Drawbacks of this approach are discussed in Golub et al. (2011). They explain that the CET approach leads to significant differences in returns to land in the same AEZ persisting over time. Another disadvantage is discussed by Hertel et al. (2010), who point out that with symmetric elasticities of transformation, the ease of conversion from e.g. cropland to forest land is the same as from forest land to cropland which obviously contradicts reality. A study by AgMIP summarizes the approaches with a statement that "(a)ll models use a different nesting structure and there is little evidence that favors one structure or another" (Schmitz et al. 2014, p. 72).

Our approach to model land use is also based on the GTAP-AEZ database and on nested CET functions. However, it differs from the existing approaches mentioned above, since in DART-BIO each annual crop does not have a unique land price but land prices for different annual crops are identical. We argue that farmers can rotate between annual crops easily. In fact, rotations systems persist to keep the soil healthy and fertile.

In the agricultural production functions of DART-BIO, we use a low elasticity of substitution between land and other factors of production.[1] This implies that land cannot be easily substituted by labor, capital or energy, so that the availability of crop land constrains crop production, which in turn increases mainly by productivity gains. This assumption is based on the observation that increases in yields are accompanied by even larger increases in land prices in many parts of the world. In fact, the intensification of agriculture has contributed the most to the growth in world agriculture output during the 1960-1990 period (Fuglie et al. 2012). However, during the last two decades, its contribution has substantially decreased. The implications of these assumptions and their effects on future simulations are explained in the next section where the new land-use version of the DART model (DART-BIO) is introduced.

[1] Our elasticities of substitution between land and other primary factors differ slightly between developed (0.2) and developing countries (0.25) and are lower compared to other global models (e.g. 0.8 in the AIM model, 0.5 in the ENVISAGE model (Robinson et al. 2014))

3. DART-BIO

DART-BIO is a detailed land use version of the DART model[2], which is a multi-sectoral, multi-regional recursive dynamic CGE model of the world economy. DART-BIO focuses on the heterogeneity of land, the complex production of biofuels and includes several activities/commodities not present in the original GTAP database. DART-BIO is calibrated based on the GTAP 9 database (Aguiar et al., 2016) , which represents the global economy in 2011 The DART-BIO model has 21 regions, 38 sectors, 51 products and 21 factors of production.

3.1. The DART-BIO database: regional, sectoral and factor details

As the focus of the model is to analyze the dynamic effects of biofuel and land use policies, the regional aggregation is carefully chosen to include the main biofuel producing and consuming countries such as the United States of America (USA), Brazil (BRA) and Germany (GER) (Table 1). The regional detail also includes countries where there are main land use changes either due to biofuels production or where major changes in population, income and consumption patterns are expected to emerge (e.g. Malaysia, Indonesia and China).

[2] The Dynamic Applied Regional Trade (DART) model was developed in the late 1990's at the Kiel Institute for the World Economy. It has been widely applied to analyze international climate policies (e.g. Springer 1998; Springer 2002; Klepper and Peterson 2006a,), environmental policies (e.g. Weitzel et al. 2012), energy policies (e.g. Klepper and Peterson 2006b), and agricultural and biofuel policies (e.g. Delzeit et al., 2018; Schuenemann and Delzeit, 2019) among others.

Table 1: List of regions in DART-BIO

Central and South America		**Europe**	
BRA	Brazil	FSU	Rest of former Soviet Union
PAC	Paraguay, Argentina, Uruguay, Chile	CEU*	Central European Union with Belgium, France, Luxembourg, Netherlands
LAM	Rest of Latin America	DEU*	Germany
		MED*	Mediterranean with Cyprus, Greece, Italy, Malta, Portugal, Spain
Middle East and Northern Africa		MEE*	Eastern European Union with Austria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Romania, Bulgaria, Croatia
MEA	Middle East and Northern Africa	NWE*	North-Western European Union with Denmark, Finland, Ireland, Sweden, United Kingdom
AFR	Sub-Saharan Africa	RNE	Rest of Northern Europe: Switzerland, Norway, Lichtenstein, Iceland
Asia		**Northern America**	
CHN	China, Hong Kong	CAN	Canada
IND	India	USA	United States of America
EAS	Eastern Asia with Japan, South Korea, Taiwan, Singapore		
MAI	Malaysia, Indonesia	**Oceania**	
ROA	Rest of Asia	ANC	Australia, New Zealand, Rest of Oceania
RUS	Russia		

*Members of the European Union

To adequately model biofuel production several key sectors need to be considered independently. Some of these sectors are not explicitly included in the original GTAP database and therefore need to be carved out from embedded sectors. Thus, 26 new sectors/products have been added to the standard GTAP database to model in total 43 sectors and 51 products (Table 2). The current DART-BIO model includes bioethanol production from sugar cane/beet, wheat, maize, other grains and agricultural residues; and biodiesel production from palm oil, soybean oil, rapeseed oil, other oilseed oils and used cooking oil. DART-BIO explicitly accounts for the by-products generated during the production process of biofuels. Dried distillers grains with solubles (DDGS) are by-products of the production of bioethanol from grains and oilseed meals/cakes are by-products of the vegetable oil industry. Thus, unlike the standard GTAP database, we differentiate between production activities and commodities, which allows to model joint production in the bioethanol and vegetable oil industry.

In addition, as biofuel consumption targets in the European Union are set according to the use of renewable energy in the road transport sector, the DART-BIO model includes separate sectors for motor gasoline and motor diesel.

Table 2: List of sectors (industries) and products (goods) in DART-BIO

PDR	**Paddy rice**	COL	**Coal**
WHT	Wheat	**CRU**	Oil
MZE	Maize	**GAS**	Gas
GRON	Other cereal grains	**MGAS**	Motor gasoline
PLM	Oil Palm fruit	**MDIE**	Motor diesel
RSD	Rapeseed	**OIL**	Petroleum and coal products
SOY	Soybean	**ELY**	Electricity
OSDN	Other oil seeds	**ETHW***	Ethanol from wheat
C_B	Sugar cane and sugar beet	**ETHM***	Ethanol from maize
STR	Agricultural Residuals	**ETHG***	Ethanol from other grains
AGR	Rest of crops	**ETHS**	Ethanol from sugar cane
OLVS	Outdoor livestock[1]	**ETHC**	Cellulosic Bioethanol from agricultural residues
ILVS	Indoor livestock[2]	**BETH**	Bioethanol
PCM	Processed animal products	**BDIE**	Biodiesel
PLMoil*	Palm oil	BDIE_PLM	Biodiesel from Palmoil
PLMmeal*	Palm meal	UCOME	Biodiesel from used cooking oil
RSDoil*	Rapeseed oil	**CRPN**	Other chemical rubber plastic prods
RSDmeal*	Rapeseed meal	**ETS**	Paper, minerals and metals
SOYoil*	Soybean oil	**OTH**	Other goods and services
SOYmeal*	Soybean meal	**FRS**	Forestry
OSDNoil*	Oil from other oil seeds	FRI	Forest related industry
OSDNmeal*	Meal from other oil seeds		
VOLN	Other vegetable oils		
SGR	Sugar		
FOD	Rest of food		
FRI	Forest related industry		
DDGSw*	DDGS from wheat		
DDGSm*	DDGS from maize		
DDGSg*	DDGS from other cereal grains		
UCO	Used cooking oil		

Source: Delzeit et al. (2021)

Note: New products are highlighted in blue. All goods are produced by an analogous industry, except were indicated by an asterisk (*). Bioethanol and DDGS are jointly produced by the bioethanol industry (3 types of industries); and oilseeds oil and meal are jointly produced by the vegetable oil industry (4 types of industries). [1] Includes cattle, raw milk, wool; [2] includes animal products nec.

The DART-BIO model has been extended to incorporate the GTAP 9 land use and land cover database (Baldos and Hertel 2012) (see Section 2.1). Thus, we use 18 GTAP-AEZs, covering 18 different lengths of growing period spread over 18 different agro-ecological and climatic zones. By using the GTAP-AEZ framework, the current version of the DART-BIO model accounts for land heterogeneity. Within each AEZ and region, land is allocated to different uses (i.e. cropland, pasture and forest) via a CET structure.

The construction of the DART-BIO database can be found in great detail in Delzeit et al. (2021).

3.2. The theoretical structure of the DART-BIO model

As in all CGE models, the DART-BIO model consists of behavioral equations that describe the economic behavior of each agent in the model, identity equations that impose constraints in the model to ensure market clearing, macro closure rules that determine the macroeconomic equilibrium conditions of the model and a detailed empirical database consistent with the model equations. A detailed description of the DART-BIO model can be found in Delzeit et al. (2018).

The economic structure of DART-BIO is fully specified for each region and covers production, investment, and final consumption by consumers and the government. DART-BIO is based on microeconomic theory. In each region, the economy is modelled as a competitive economy with flexible prices and market clearing conditions. Agents represented in the model are consumers, who maximize utility, producers, who maximize profits, and regional governments. All industry sectors operate at constant returns to scale. The goods are produced by a combination of intermediate inputs (energy and non-energy inputs) and primary factors (labor, capital and land in the agricultural sectors). The produced goods are directly demanded by regional households, governments, the investment sector, other industries, and the export sector.

A representative household receives all income generated by providing primary factors to the production process. Disposable income is used for maximizing utility by purchasing goods. The consumer saves a fixed share of income in each time period which is invested in production. The government provides a public good financed by tax revenues. Regions are connected via bilateral trade flows, where domestic and foreign goods are imperfect substitutes and distinguished by country of origin (Armington assumption). Factor markets are perfectly competitive and full employment of all factors is assumed. Labor and capital are assumed to be homogeneous goods, mobile across industries within regions but internationally immobile. Labor and capital mobility ensures uniform wages and capital rents across industries. However, their degree of mobility is restricted by the elasticities of substitution between them, other primary factors and intermediate inputs. The primary factor land is used in agriculture and forestry and exogenously given.

The recursive-dynamic character of the model stems from the fact that it solves for a sequence of static one-period equilibria for future time periods, which are connected through capital accumulation and changes in labor supply. The dynamics of the model are mainly driven by exogenous driving forces. Capital accumulation is driven by the savings rate, the gross rate of return on capital, and thus the endogenous rate of capital accumulation. The capital stock of the next period is altered by the current period's investments and depreciation. The allocation of capital among sectors follows from the intra-period optimization of the firms. The savings behavior of regional households is characterized by a constant savings rate over time.

Labor supply and productivity are determined by changes in labor force, the rate of labor productivity growth, and the change in human capital accumulation. An increase in effective labor implies either growth of the human capital accumulated per physical unit of labor, growth of the labor force or total factor productivity, or the sum of all. DART assumes constant, but regionally different labor productivity improvement rates, constant but regionally different growth rates of human capital, and growth rates of the labor force according to current projections of participation rates taken from the PHOENIX model (Hilderink, 2000) and in line with recent OECD projections. Population growth is taken from the OECD (2018).

The DART-BIO model includes greenhouse gas emissions associated with economic activities based on the GTAP- database for CO_2 (Lee, 2008; Aguiar, 2016) and based on work Chepeliev (2020) for non-CO_2.

4. Defining and implementing five model specifications

In this section, we develop – as alternatives to our *standard* DART-BIO model setup – six model specifications, all of them are based on DART-BIO and we test for each of them the economic implications of their different assumptions. In this way, we aim to make transparent how different modelling approaches influence the results of simulation studies. We also show that these model differences can be the reason for the large variation in results that are observed in the different studies mentioned above.

In order to illustrate the implications of the different model specifications we use as a policy shock the much-debated impact of biofuel policies on markets for agricultural commodities. In fact, we implement two scenarios for higher demand for biofuels using the different specifications of the DART-BIO model (see section 5).

The six different model specifications relate to three different model structures and three parameter choices that we consider to be crucial factors influencing the modeling results. With the three model structures we reconstruct different approaches used in current models to represent the complex production and value chains of agricultural goods and to describe the economic forces of land use. The three parameter choices address the importance of choosing, on the one hand, the elasticity of substitution between land and the capital, labor, and energy composite, and on the other hand, the elasticity of substitution between different feedstuffs in livestock production. An overview of the different model specifications is provided in Table 3.

4.1. Changes in model structure

There are three features that distinguish models that aim to model the reaction of agricultural markets to policy shocks, especially to bioenergy policies. One fundamental difference concerns the role of land prices as a driver of the allocation of crops to particular areas. If land has a uniform price, crops will be moved to their highest value uses if some external shock is imposed. If land prices are crop specific each crop has a certain inherent profitability that is not much influenced by the prices prevailing on land market. There are arguments in favor and against both approaches, hence we will show how they influence the results of policy studies.

Another important feature is the treatment of joint production processes in agriculture. In standard CGE models, agricultural production functions have one single output that is supplied to the market whereas other by-products are assumed to remain on the farm. However, in reality, a certain type of biomass grown is often turned into several different products and sold to different markets. Whereas some CGE models explicitly include by-products, others concentrate only on the main product. We analyze the impact of these assumptions and show the importance of by-products as an income source for farmers and as a substitute for animal feed.

4.1.1. Land Prices

As far as the modeling of the economic incentives for certain land use decisions is concerned one important structural difference in models is the treatment of land prices. Most models assume that land prices, in other words, land rents depend on the crop grown, hence these models have a different land price for each crop within a region. These modelling approaches work with the implicit assumption that the land rent is determined by the profitability of crop grown and not by some land market that allocates land to the most profitable crop. Consequently, changes in relative prices of agricultural commodities would not affect directly the relative prices of land used for the different commodities. As explained in section 3.3, DART-BIO uses a nesting structure with a uniform land price for all annual crops. In this case, the profitability of certain crops is directly influenced by crop prices but land prices are determined by the profitability of all crops within an AEZ. We test the effect of this difference in model structure in the model specification *NestingLand* (see table 3) by adding a nest for annual crops in the CET function for land. With this approach we can identify how assumptions about the flexibility for moving land into different uses influences the results of policy studies.

4.1.2. Joint production in agriculture

Another important driver of the results of simulation exercises is the treatment of agricultural production functions in the model. Agricultural production has historically turned from a single output production with residues remaining on the farm to a multi-product industry, in technical terms from a single one-dimensional production function to a joint production function with several outputs. For many industries it is not at all clear whether there still exists a dominating product. E.g., growing oilseeds (soybeans, rapeseed) yields oils and animal feed, so does maize production. Several CGE models do not implicitly include by-products from biofuel production (e.g. the model ENVISAGE (van der Mensbrugghe 2009) or Banse et al. (2008), while Taheripour et al. (2010)[4] show that price effects from biofuel policies are larger if by-products from biofuel production are not modelled. The effect of ignoring the joint production of meals and oils as well as DDGS and bioethanol is tested in the model specification *NoByProd.* In this specification, only the oils (soy oil, rapeseed oil, palm oil and other seed oils) are modelled independently, the meals remain in the residual vegetable oils sector (VOLN) and enter the livestock sectors from this aggregated sector. In the case of bioethanol production, the share of grains related to the production of DDGS in the joint production function enters directly as feedstuff to the livestock sectors.

4.2. Changes in parameter choices

CES production function specifications vary in the different CGE models. Robinson et al. (2014) provide an overview and show that elasticities of substitution between land and other inputs for agricultural production range between 0.2 and 1.2. In the model specification *Elast08* a higher

[4] Note that by-products from the vegetable oil industries are not considered

substitution between land and the capital, labor, energy nest is simulated. While in the *standard* DART-BIO model, this elasticity is set to 0.2, it is set to 0.8 in this specification.

When by-products are integrated into the database, questions arise on how easily they can be substituted with other feedstuff. As elasticities are not available in the literature, we test the sensitivity of this parameter by increasing it to 4 and by reducing it to 0.5 compared to an elasticity of 2 in the DART-BIO model.

Table 3: Overview of model specifications

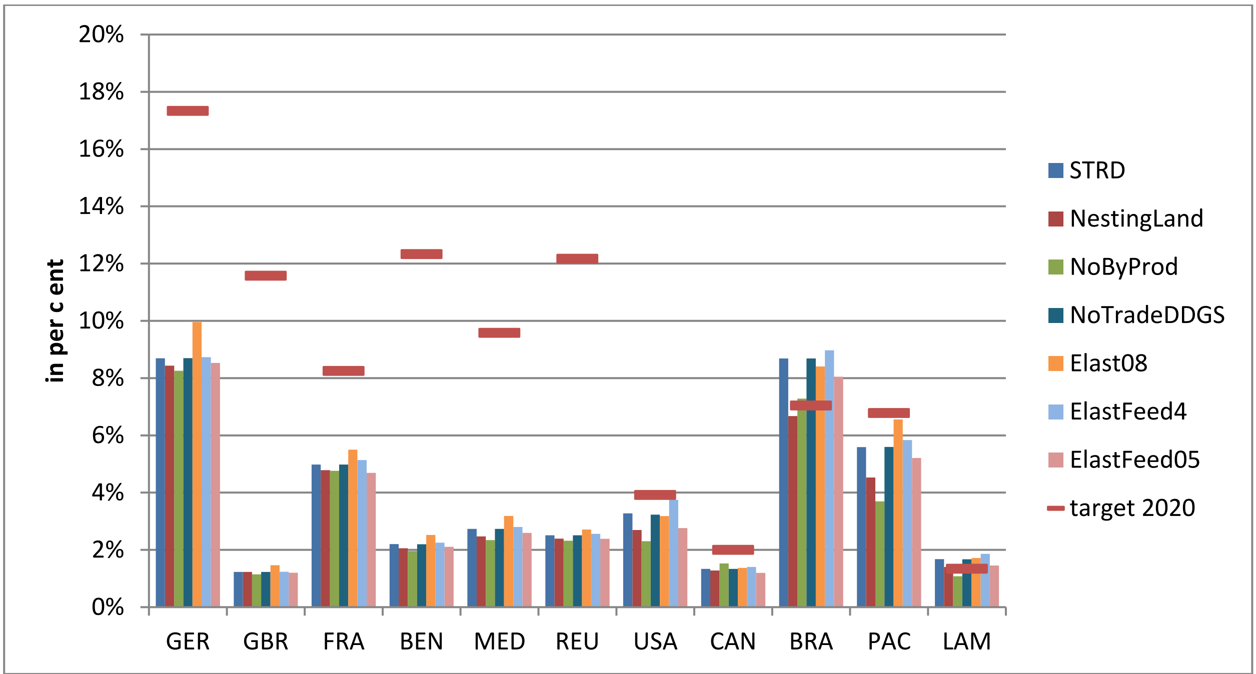
Specification	**Model structure**	**Parameter choice**
STRD	Standard DART-BIO: - CET function that allows a differentiated land price for annual crops - Explicit modelling of by-products - DDGS is traded bilaterally	Standard DART-BIO: - Elasticity of substitution between land and the capital, labor, energy nest is 0.2-0.25 - Elasticities of substitution for feedstuff entering livestock production is 2[5] CET elasticities for annual crops range from 0.20 to 0.59 (see Table A1)
NestingLand	-uniform land price	CET elasticities for the first three levels as standard DART-BIO
noByProd	By-products are not modelled.	As standard DART-BIO
Elast08	As standard DART-BIO	Elasticity of substitution between land and the capital, labor, energy nest is set to 0.8 (0.2-0.25 in the standard DART-BIO)
ElastFeed4	As standard DART-BIO	Elasticities of substitution for feedstuff entering livestock production is set to 4 (2 in the standard DART-BIO)
ElastFeed05	As standard DART-BIO	Elasticities of substitution for feedstuff entering livestock production is set to 0.5 (2 in the standard DART-BIO)

[5] This elasticity is chosen based on the following procedure. After a literature review (O'Brian 2011, Agricultural Market Research Centre 2012, USDA 2011) we concluded that is technical and nutritional possible to double DDGS use in the US. We then run a detailed sensitivity analysis with different elasticities and selected the most appropriated one (a relatively high substitution elasticity, 2).

5. Results

Figure 3 shows the shares of biodiesel in total diesel consumption (fossil and biodiesel) in 2020 for the reference runs of the different model specifications. Taking Germany (GER) as an example, in the standard DART-BIO simulations biodiesel consumption needs to be increased by 8.6 percent points to fulfil the national target. With a higher share in the reference scenario, under the *Elast08 specification* consumption must only be increased by 7.4 percentage points to meet the targets in 2020. Most notably are the impacts in Brazil (BRA) and the other Latin American countries (PAC and LAM) where the quota are binding under some model specifications but not binding under others.

Figure 1: Shares of biodiesel on total diesel consumption for the reference scenarios under different model specifications in 2020



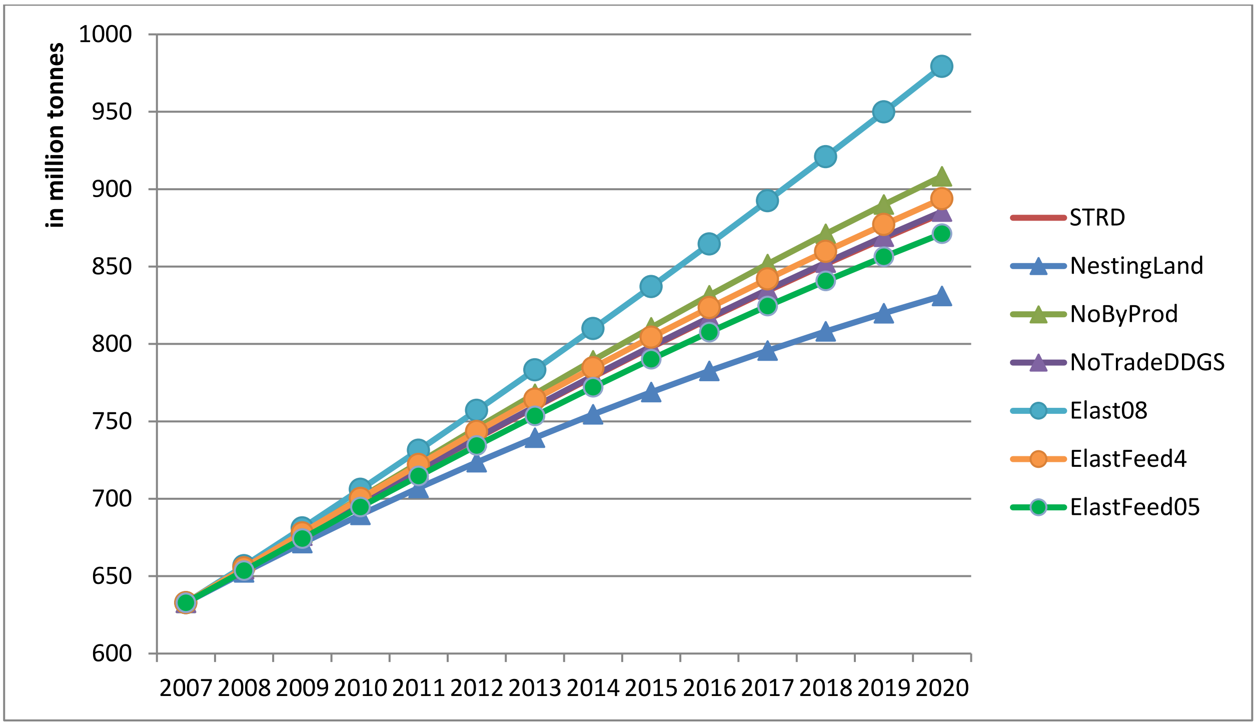
Note: Selected countries are displayed. Data for other regions are available upon request.

This implies that price differences of biofuel policies are not only driven by structural differences in the model specification, but also by relative differences on the simulated reference scenarios of agricultural markets. This effect is analyzed in in the following section.

5.1.1. *The effect of model specifications on reference runs*

The model structure and parameter choices cause large differences in the development of future agricultural markets. Potential pathways of wheat production for the different model specifications are illustrated in Figure 4. It shows that in case of wheat, the way land use is modelled causes the largest variations in the results. The *NestingLand* specification leads to a global wheat production which is 15% lower than that in the *Elast08* specification in 2020. As explained in the former section, this is caused by the different development of factor prices.

Figure 2: Global wheat production under different model specifications (reference scenario)



Accordingly, Table 4 illustrates that the changes in the global production of biofuels already under the reference scenarios are quite different: in the *standard* DART-BIO reference (*STRD*), global production of bioethanol increases by 7.6% and biodiesel by 14.5% between 2007 and 2020. Higher prices of annual crops under the *NestingLand* reference scenario cause a relative small increase in global production. In contrast, higher substitutability between land with the capital-labor-energy nest (*Elast08*) results in lower land pressure and crop prices (cp. Figure 6), and therefore in a significant increase in biofuel production.

Table 4: Percent change in global biofuel production between 2007 and 2020 under different model specifications (reference scenarios)

	STRD	NestingLand	NoByProd	NoTradeDDGS	Elast08	ELASTFEED4	ELASTFEED05
BETH	7.6	6.6	7.1	7.6	21.0	7.9	7.2
BDIE	14.5	12.0	10.6	14.5	21.6	15.5	13.0

Note: BDIE= biodiesel, BETH= bioethanol

These different production levels of biofuels in the reference scenarios have major impacts on the additional quantity that must be produced in order to meet the biofuel target in 2020. For instance, global production of biodiesel should increase by 159% in the *standard* DART-BIO model, by 132% under the *Elast08* specification and by 182% under the *NestingLand* specification (when compared to their respective 2020 reference scenarios).

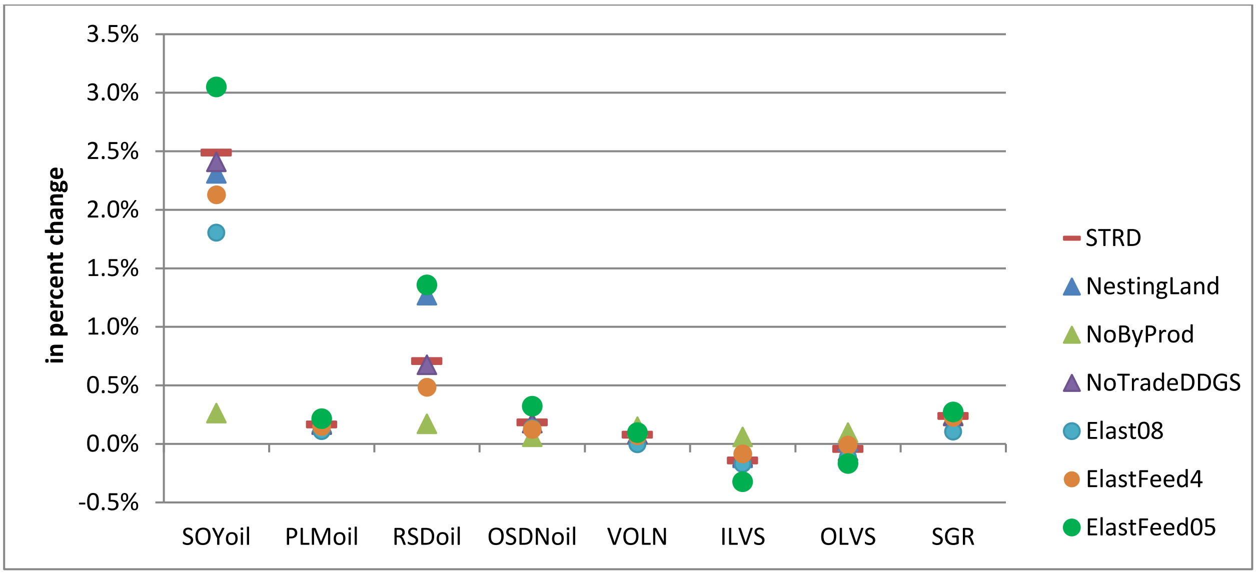
To make the results comparable independent of these differences in demand shocks across model specifications, we created an artificial 20% biofuel share scenario.

5.1.2. Effects along the value chain of biofuels and other biomass-based processed products

So far, we have shown how different model specifications influence the results of scenario analyses for the markets of agricultural raw materials. In the reminder we look at the impact of different model structures and parameter values on markets further up in the supply chain of products based on biomass. The most remarkable effects occur in the markets for vegetable oils and animal feed. Again, we take the test case of a plus 20% biofuel share as the scenario against which we compare different modeling approaches.

The differences in price changes due to higher biofuel demand are mainly driven by the way in which by-products are integrated into the model. When meals from oilseeds and DDGS are not implicitly integrated into the database and the model (the *NoByProd* specification), the results differ strongly for some agricultural commodities from the case where by-products are appropriately taken into account. Prices of vegetable oils that are produced with a high share of meals such as soy oil and which are intensively used for biodiesel production increase by less than 0.5% in the NoByProd specification whereas they increase by 2.5% in the *standard* DART-BIO specification which includes by-products (see Figure 9). This is simply due to an artefact in the models without byproducts, namely that the price effect is computed towards the total quantity of soy produced instead of the quantity of soy oil which is the input for biodiesel production. Since each ton of soybean processing yields roughly 80% meal and 20% oil, by-product modeling is essential.

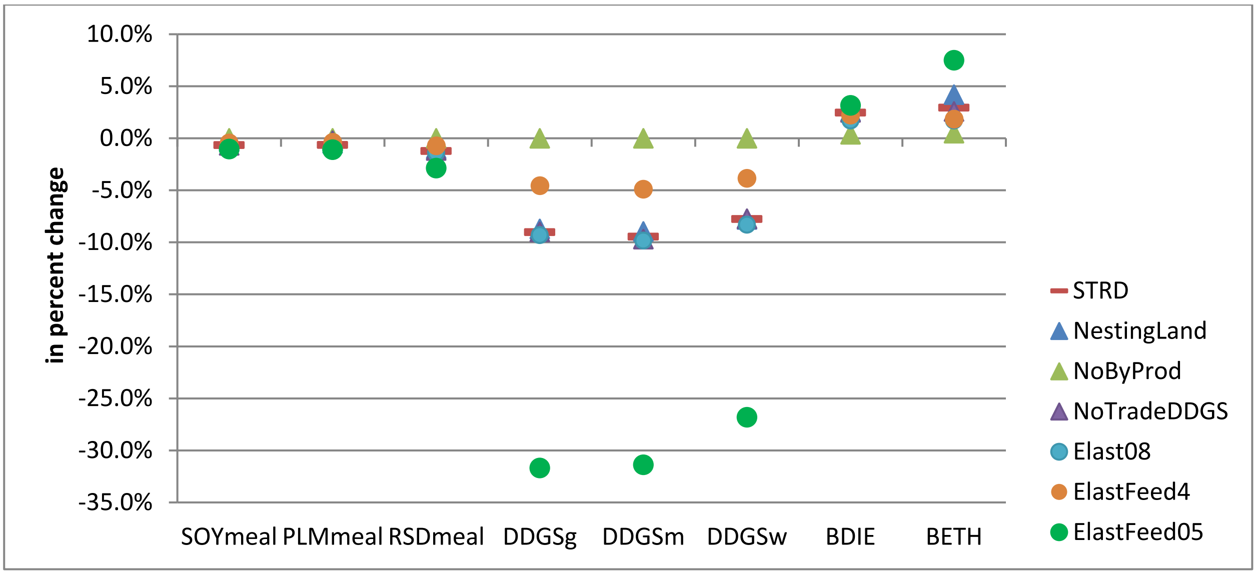
Figure 3: Change in global average prices in 2020 caused by a plus 20% biofuel share under different model settings (changed model structure in triangles, changed parameter settings in circles)



SOYoil= soy oil, PLMoil=palm oil, RSDoil= rapeseed oil, OSDNoil: Oil from other oil seeds, VOLN: other vegetable oils, ILVS= indoor livestock, OLVS= outdoor livestock, SGR= sugar

The other extreme is palm oil where no significant feedstuffs occur. Rapeseed with a roughly 50/50 share is in the middle. The small price effect for soy (oil plus meals) in the *NoByProd* specification leads to a situation in which there is hardly any price increase in biofuels, whereas it is in the order of 2 to 3 percent in the case with recognition of by-products (Figure 9).

Figure 4: Change in global average prices in 2020 caused by a plus 20% biofuel share under different model settings (changed model structure in triangles, changed parameter settings in circles)



SOYmeal= soy meal, PLMmeal=palm meal, RSDmeal=rapeseed meal, DDGSg= Dried distillers grains with solubles (DDGS) from other grains, DDGSm=DDGS from maize, DDGSw=DDGS from wheat, BDIE=biodiesel, BETH=bioethanol

At the same time, livestock prices go in a different direction. If by-products are not modeled, a higher demand for soy increases feed prices with a subsequent slight increase of livestock prices by 0.1%. In contrast and more realistically, the explicit modeling of by-products results in higher prices for oils while prices for meals and DDGS drop. The livestock market then experiences prices falling by up to -0.3%, admittedly a small number (Figure 8 and 9). Figure 9 illustrates that the divergence of price effects for biofuels is, in a first instance, related to the extent to which meals are produced (prices increase from around zero *NoByProd* to 3% *STRD*), and then related to the assumptions on the elasticity of substitution in animal feed (prices increase further, up to 7.5% for bioethanol under *ElastFeed05*).

As mentioned above, the results are influenced by the way in which the use of by-products as animal feed are modeled in the livestock production function. There are several feedstuffs that enter the production function for livestock. By how far they can be substituted depends on the composition of animals in the livestock sector and their nutritional requirements. We test the impact on biofuel prices with two specifications of this substitutability, a high elasticity of substitution (4 in *ElastFeed4* versus 2 in the *standard* DART-BIO case) and a low elasticity of substitution (0.5 in *ElastFeed05).*

The elasticity of substitution between feedstuffs has a strong impact on DDGS and bioethanol prices (Figure 10). Bioethanol prices increase in the *standard* DART-BIO specification by 2.5%, they are slightly lower (1.7%) if by-products are easily substitutable with other feedstuff in the livestock sector (*ElastFeed4*). However, they increase by 7.4% if the elasticity of substitution in the livestock feeds is low (*ElastFeed05*). The strongest differences occur in the USA where the demand for DDGS essentially determines the price increases for bioethanol. The standard assumptions in DART-BIO lead to a price increase of 4.1% in the USA. Under the low elasticity scenario where DDGS prices fall by over 30%, bioethanol needs to be sold at a price 10.8% higher relative to the non-quota case.

There are complex interactions taking place in determining these strong effects. Maize and DDGS directly compete in the feed market and the former is the dominating input in US bioethanol production. The bioethanol quota of 20 percent modeled here leads to DDGS prices lower by almost one third in the low elasticity case. In fact, an even larger price drop has occurred on the

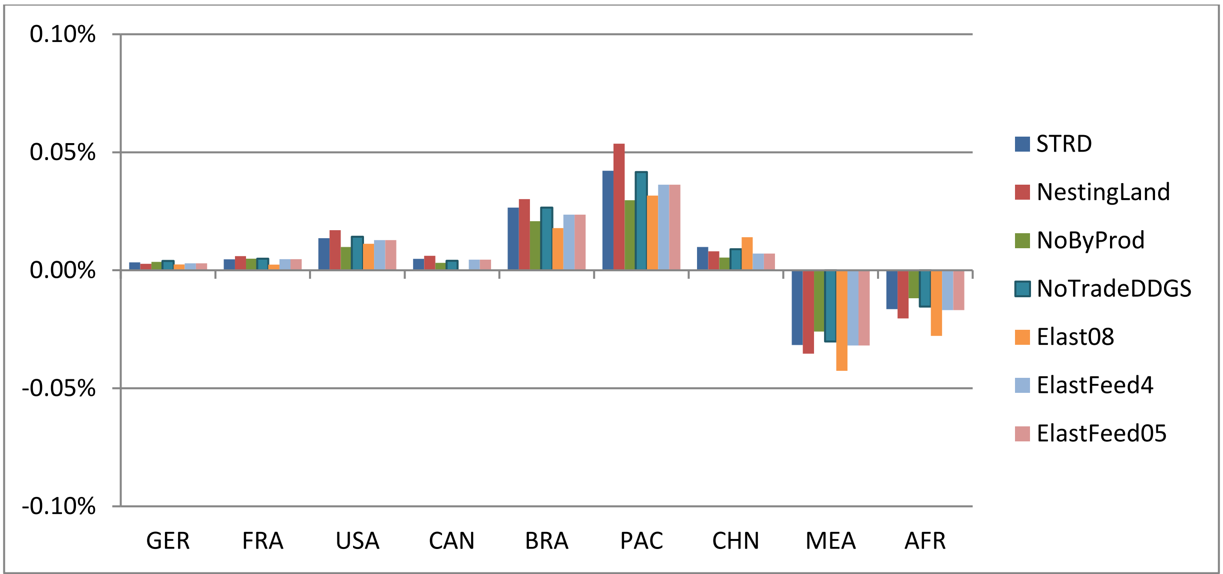
US DDGS market when the bioethanol production had strongly expanded (Hoffman and Baker 2010). The DART-BIO model also shows that DDGS begins to being exported at such low prices. This export market for DDGS has only developed in conjunction with the biofuel support policies. Under the low elasticity case maize and DDGS can be substituted only modestly. This leads to a shortage of maize and an oversupply of DDGS with little possibility of substitution. The contrary happens with a high elasticity of substitution where DDGS as feed is substituted for the previously used maize and the price effects for the DDGS and for bioethanol are more moderate.

The interaction of the animal feed and meat markets with the biodiesel market are much smaller because soy meal is the dominating feedstuff with the consequence that the additional demand for soy oil for producing biodiesel is limited by the competition with other oils such as rape and palm oil and the large quantities of soymeal already in the market have little influence on the livestock production.

The introduction of by-products in the modeling framework together with carefully taking into account upstream effects of the crop value chain towards food, feed, and biofuels has an significant impact on the magnitude of the price effect of biofuel quotas. The results indicate that the different modeling approaches used in the literature and the value choices of some crucial parameters can explain a considerable part of the variation in the results that have been reported for the effects of biofuel policies. Despite the fact that we have used moderate biofuel expansion policies in the analysis, the differences in results are already quite remarkable.

This is also the case for macroeconomic impacts of biofuel quotas. In regions on the European Union (see e.g. Germany and France in Figure 10) as well as Canada the gross domestic product (GDP) is hardy affected by biofuel policies. Net exporters of agricultural products such as the USA, Brazil and PAC (Paraguay, Argentina, Uruguay, Chile) benefit from biofuel quotas. Their GDPs increase by up to 0.05%. Brazil for example, increases its net exports of soybeans (1%) and Bioethanol (60%). Also total demand increases with higher revenues from trade. GDPs of Middle-East and Northern Africa (MEA) and Sub-Saharan Africa (AFR) are reduced. In case of MEA, a net importing region, total demand decreases by (0.02%) with rising commodity prices. The decline in GDP under biofuel policies in Sub-Saharan Africa is caused by contradicting factors: while net exports of staple crops rise by up to 1.4% and net imports of processed food decrease by 2.7%, higher prices at the world market cause total consumption to decrease and therefore GDP to fall.

Figure 5: Change in gross domestic product in 2020 compared to reference runs for selected regions



6. Summary and conclusions

We have used the DART-BIO model to analyze within a single model the impact of different approaches for modelling land use, land use change and the markets for the different forms of agricultural products and their further conversion into consumption goods. It turns out that the particular modelling approaches chosen strongly influence the results of numerical assessments of policy options. We therefore present in detail the assumptions and structural equations for modelling the value chain from agricultural raw materials to the many final consumption goods which use agricultural products as an input. As an example for the policy analysis we use biofuel policies to assess how the quantification of the economic consequences of these policies is influenced by the setup of the models used.

Our analysis illustrates how the differences in scenario results reported in the literature can be caused 1) by different representations of complex production and value chains of agricultural goods, especially the multi-functionality of many agricultural raw materials and the multi-product aspects of many farming activities, 2) by differences in methods for modelling land use, 3) by different choices of some critical model parameters, and 4) substantial differences in model structures such that a direct comparison seems to be almost impossible.

We find that the impact of biofuel policies on the production of crops is particularly sensitive to the way in which land markets are modelled. As the way in which land markets allocate land rents are often very region specific there is no a priori correct answer. Our analysis allows to derive two conclusion on this: 1) we show that high elasticities of transformations used in some models and reproduced in one of the model specification is probably not a realistic feature, 2) models using separate land prices for each annual crops tend to overestimate the impact of a demand shock. We show that this is the case for rape seed and a biodiesel demand shock. At the same time, with this specification other annual crops are hardy affected which does not seem to represent the market effect in reality.

Further down the value chain, the variation in results can be attributed to the way in which by-products are (or are not) included into the database and the subsequent modeling. Finally, price changes of biofuels due to biofuel policies are also influenced by the demand responses in other industries such as the livestock sector. An integrated modeling of the complete value chain of biomass in all potential uses is therefore an important aspect for getting realistic results.

Most studies are forward looking exercises that compare future policy outcomes with a no-policy baseline. It is obvious that different model setups also lead to different baselines and – as a consequence – to different relative impacts of policies. However, we find that these differences may be quantitatively important and can explain some of the scenario results. We show by how much the model specifications already differ in different reference runs. The announced biofuel shares that are commonly used to analyze the impact of those policies are binding under some model specifications but not binding under others in some regions.

Therefore, we implemented an artificial scenario where the shares of biofuels in 2020 under each of the reference scenarios are increased by 20% such that there is the same quantity shock. The detailed analysis of this theoretical scenario illustrates how such a policy can have strong economy-wide repercussions and how different model setups influence these repercussions. For some parameter choices we find model responses that look quite unrealistic such as very large increases in the capital intensity of agriculture in China.

The example of DDGS is a particular illuminating one. It illustrates that policies may create new markets that had previously not existed and that change the market outcomes drastically. The DDGS example suggests that it is important to include potential markets into forward looking analyses. Although it is not included in the current analysis with the DART-BIO model, the development of markets for waste and residues such as used cooking oil for biodiesel production has already shown important impacts on markets for biofuels. Such potential responses of market actors should become part of forward looking studies, it presents quite a challenge to predicting new market opportunities but ignoring it would make scenario analysis less reliable.

The analysis of biofuel quotas is only one of many cases of policies that affect land use and biomass production. It illustrates the importance of treating model and parameter specifications for particular policy analyses very carefully and to make transparent both the structural approaches to the models as well as the choice of important model parameters.

We believe that the results presented here call for a different treatment of numerical policy analyses. The harmonization of major drivers of baseline developments such as GDP, productivity growth, climate change, and many others is not sufficient for getting robust results and for deriving reliable policy recommendations. A thorough discussion about model structures and parameter choices needs to accompany the presentation of results. This is not only important for the discourse among modelers. The policy makers who are to be informed by these studies should also get presented not necessarily the formal details of modeling approaches but a narrative of the model philosophy and the interactions taken into account. Only with this information the applicability of certain modeling approaches for a particular policy question can be appropriately assessed.

A further conclusion can be drawn from these insights. Since certain parameter values have no strong empirical base, it is therefore a judgement which one to choose. Sensitivity analyses can shed some light on their impact. However, including stakeholders in the early phase of developing a scenario study could extract additional information from practitioners and makes the analysis more credible to them. This is also important for potential repercussions such as the development of new markets or new technologies where the insights of practitioners can both lead to a more informed narrative and to a better consensus between modelers and users of scenario analyses.

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Annex

Table A1: Elasticities of transformation

	GER	GBR	FRA	SCA	BEN	MED	REU	USA	CAN	ANZ	JPN	RUS	FSU	BRA	PAC	LAM	CHN	IND	MAI	SEA	MEA	AFR	ROW
CET1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CET2	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.15	0.14	0.17	0.11	0.21	0.21	0.21	0.21	0.11	0.21	0.21	0.21	0.21	0.15	0.21	0.11
CET3	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.32	0.32	0.3	0.15	0.22	0.22	0.22	0.22	0.3	0.22	0.22	0.22	0.22	0.24	0.24	0.15
CET4	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.55	0.58	0.59	0.20	0.23	0.23	0.23	0.23	0.59	0.23	0.23	0.23	0.23	0.35	0.35	0.20

Source: Abler 2000 and Salhofer 2000 used in the OECD's PEM model; The OECD model only covers developed countries plus Mexico, Turkey, and South Korea. Therefore, we had to assume certain similarities for several countries. CET1 denotes the nest between forest and agricultural land, CET2 the nest between cropland and pasture land, CET3 the nest between land for different perennial and annual crops. CET4 is only used for one model specification; it denotes the elasticity of substitution between land for annual crop.

Table A2: Income elasticities

	GER	GBR	FRA	SCA	BEN	MED	REU	USA	CAN	ANZ	JPN	RUS	FSU	BRA	PAC	LAM	CHN	IND	MAI	SEA	MEA	AFR	ROW
PDR													0.36	0.21	0.17	0.27	0.56	0.56		0.72	0.43	0.68	0.61
WHT	0.02	0.02	0.02	0.02	0.02	0.03	0.13			0.03		0.2	0.38	0.21	0.17	0.33	0.55	0.56		0.62	0.43	0.6	0.4
MZE	0.02	0.02	0.02	0.02	0.02	0.03	0.15	0.01	0.02	0.02		0.2	0.39	0.21	0.24	0.28	0.54	0.56	0.53	0.62	0.41	0.64	0.41
GRON	0.02	0.02	0.02	0.02	0.02	0.03	0.13		0.02	0.02	0.02	0.2	0.38	0.21	0.19	0.26	0.55	0.56	0.53	0.63	0.4	0.67	0.34
PLM																0.38			0.53	0.41		0.67	0.5
RSD		0.03		0.02		0.03	0.11			0.02		0.2	0.32					0.56			0.34	0.47	0.05
SOY		0.03			0.02	0.04	0.11			0.02		0.2	0.25		0.24	0.26	0.03	0.56	0.53	0.43	0.38	0.68	0.08
OSDN				0.02		0.03	0.12			0.02		0.2	0.29			0.36		0.56	0.53	0.58	0.41	0.68	0.23
C_B	0.02	0.02	0.02	0.02	0.02	0.03	0.25	0.01	0.02	0.02			0.4		0.17	0.19		0.56	0.3	0.64	0.53	0.45	0.3
OLVS	0.86	0.89	0.87	0.88	0.92	0.86	0.77	0.9	0.88	0.87	0.85	0.7	0.77	0.68	0.73	0.7	0.82	0.92	0.81	1.06	0.8	1.05	0.93
ILVS	0.86	0.89	0.87	0.88	0.87	0.85	0.77	0.9	0.87	0.86	0.85	0.7	0.79	0.66	0.67	0.7	0.81	0.92	0.79	0.9	0.79	0.97	0.87
AGR	0.04	0.02	0.03	0.02	0.03	0.04	0.13	0.01	0.08	0.04	0.02	0.21	0.43	0.21	0.28	0.3	0.54	0.56	0.51	0.54	0.43	0.66	0.3
FRS	1.02	1.02	1.02	1.02	1.02	1.03	1.07	1.01	1.02	1.02	1.03	1.13	1.19	1.07	1.11	1.1	1.06	1.06	1.09	1.01	1.13	1.11	1.04
PLMoil				0.91	0.9	0.87	0.77			0.88	0.87		0.72	0.68	0.74	0.71	0.72	0.66	0.71	0.71	0.76	0.77	0.74
RSDoil	0.88	0.91	0.89	0.89	0.9	0.87	0.78	0.91	0.89	0.88	0.87		0.71		0.7	0.72	0.71	0.66	0.66	0.74	0.72	0.75	0.78

SOYoil	0.88	0.91	0.89	0.9	0.89	0.87	0.77		0.89	0.87	0.87	0.72	0.72	0.68	0.72	0.72	0.71	0.66	0.71	0.72	0.73	0.72	0.79
OSDNoil	0.88	0.91	0.89	0.9	0.9	0.87	0.77			0.88		0.72	0.71	0.68	0.69	0.72	0.71	0.66	0.71	0.7	0.75	0.7	0.78
VOLN	0.88	0.91	0.89	0.9	0.89	0.87	0.77	0.91	0.89	0.87	0.87	0.72	0.73	0.68	0.71	0.72	0.71	0.66	0.71	0.73	0.75	0.75	0.76
SGR	0.88	0.91	0.89	0.89	0.9	0.87	0.77	0.91	0.89	0.87	0.87	0.72	0.71	0.9	0.73	0.71	0.71	0.66	0.7	0.73	0.76	0.73	0.75
CRPN	1.02	1.02	1.02	1.02	1.02	1.03	1.08	1.01	1.02	1.02	1.03	1.13	1.14	1.04	1.07	1.09	1.05	1.04	1.09	1.04	1.1	1.11	1.05
BETH	0.88	0.93	0.89	0.94	0.97	0.86	0.77	0.92	0.89	1.01	1.03	0.72	0.71	1.04	1.05	1.08	0.71	1.04	1.08	1.04	0.78	1.04	0.94
BDIE	0.88	0.91	0.89	0.9	0.89	0.87	0.8	0.91	0.89	0.88				0.68	0.66	0.65	0.71		0.69	0.66			0.76
FOD	0.88	0.91	0.88	0.89	0.89	0.86	0.8	0.91	0.89	0.87	0.81	0.72	0.72	0.62	0.68	0.7	0.72	0.66	0.67	0.7	0.74	0.75	0.75
PCM	0.86	0.89	0.87	0.88	0.87	0.85	0.75	0.9	0.87	0.86	0.85	0.7	0.75	0.66	0.68	0.7	0.81	0.92	0.76	0.8	0.76	0.91	0.84
FRI	1.02	1.02	1.02	1.02	1.02	1.02	1.06	1.01	1.02	1.02	1.03	1.12	1.16	1.07	1.07	1.11	1.05	1.06	1.06	1.06	1.1	1.11	1.04
COL	1.01	1.02	1.01		1.01	1.02	1.04			1.02		1.09	1.1			1.02	1.04	1.08		1.08	1.08	1.07	1.04
CRU							1.08						1.04								1.02	1.45	
GAS	1.01	1.01	1.01	1.01	1.01	1.01	1.06	1	1.01	1.01	1.02	1.09	1.09	1.04	1.03	1.03	1.04	1.08	1.06	1.11	1.08	1.1	1.06
MGAS	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99	0.99	0.99	1.01	1.02	0.95	0.95	0.98	0.98	1.06	0.97	0.96	1	1.03	0.99
MDIE	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99	0.99	0.99	1.01	0.98	0.95	0.95	0.98	0.98	1.06	0.97	0.94	0.99	1.06	0.99
OIL	0.99	0.99	0.99	0.99	1	0.99	1	0.99	0.99	0.99	0.99	1.01	1.02	0.95	0.96	0.98	0.98	1.06	0.98	1.03	1.01	1.12	1.01
ETS	1.02	1.02	1.02	1.02	1.02	1.03	1.09	1.01	1.02	1.02	1.03	1.13	1.16	1.07	1.08	1.08	1.05	1.06	1.09	1.04	1.08	1.12	1.05
ELY	1.01	1.01	1.01	1.01	1.01	1.02	1.06	1	1.01	1.01	1.02	1.09	1.11	1.04	1.04	1.06	1.04	1.08	1.06	1.07	1.08	1.13	1.05
OTH	1.03	1.02	1.03	1.03	1.03	1.03	1.09	1.01	1.02	1.02	1.03	1.14	1.16	1.08	1.07	1.1	1.12	1.18	1.13	1.14	1.11	1.2	1.05

Source: Narayanan et al. (2012).