

Research article

The role of flexible biofuel policies in meeting biofuel mandates

Anil Markandya¹, Kishore Dhavala^{2,*} and Alessandro Palma³

¹ Basque Centre for Climate Change, Bilbao, Spain

² Nalanda University, Rajgir, India

³ Bocconi University-IEFE-Centre for Research on Energy and Environmental Economics and Policy, Milan, Italy

* **Correspondence:** Email: kishoredhavala@gmail.com.

Abstract: The paper analyzes the role of biofuel sector in three major regions (USA, European Union and Brazil). It focuses on the links between volatility in the yields of feedstock and how these yields feed through to changes in the prices of biofuel crops under different rules for managing biofuel mandates. Global Trade Analysis Project (GTAP) model has been calibrated for the years 2007–2012 to derive, endogenously, biofuel production in each year for all the three regions. Further, the study examines four different volatility variations of possible shocks to yields as representative of natural variations in the production of the feedstocks. It analyzes the impacts of changes in the mandated biofuel under the four variations to see what impact they would have principally on the prices of the key agricultural inputs linked to the biofuel sector. The model results indicate that current mandates have significant impact on the biofuel crops. The world biofuels production is expected to increase by 54% by year 2020. EU ethanol from grains and biodiesel are expected to grow by 85% and 49% respectively. The analysis observes high elasticity of substitution between fossil fuel and biofuels, which results in a greater demand for biofuels when yields of feedstocks rise and prices of feedstocks fall.

Keywords: ethanol and biodiesel productions; biofuel mandates; elasticity of substitution; volatility of prices; waivers

1. Introduction

In response to the oil supply shock of the 70s, many countries have focused on the alternative fuel sources for transportation. The United States of America (USA), Brazil and the European Union (EU), in particular have promoted biofuels through subsidies and policy regulations. The USA and Brazil have focused on corn and sugar cane for ethanol, whereas EU countries largely focused on oilseeds for biodiesel. Biofuel mandates in these regions have helped them to reduce their dependency on fossil fuels to a varying degree. Approximately 90% of the biofuel production is concentrated in these three regions, for the period 2000–2012. During this period, global biofuel production has increased from 18 billion litres to 83 billion litres [1,2].

Until 2006, Brazil was considered as a global leader in ethanol production, but the well promoted domestic ethanol policies in the USA helped the country to secure the top spot of the world ethanol production, within span of five years (2007–2012) US ethanol production has doubled from 18.5 billion litres to 38 billion litres [1]. During the same time, EU countries have designed several mandates to promote biodiesel. The noted ones are EU Biofuel Directives which set a 5.75% share for biofuels in the liquid fuel market by 2010 [3] and the Renewable Energy Directives, which imposed a target of 10% renewable energy in road transport fuels by 2020 [4]. These mandates have influenced biodiesel growth in EU; for the period 2007–2013, the biodiesel production in EU has increased from 6 billion litres to 12 billion litres [2,5].

Maze based ethanol is the most significant biofuel in the US, it has accounted 94% of all the biofuel production of the US in year 2012, the other six percent of biofuel comes from vegetable oils, animal fats and other waste oils [6]. In Brazil, half of the ethanol comes from sugar cane, whereas in EU approximately 68% of the biodiesel comes from vegetable oil production, primarily rapeseeds [7,8]. The nexus between biofuels production and food crops have generated a great interest among the biofuel and agricultural sectors.

In the past, several studies have focused on the biofuel mandates and their impacts on the food commodity prices and production. Several studies [9–12] have argued that the share of biofuel crops and feedstock production will grow significantly with the existing mandates.

These studies also have projected a sharp increase in the prices of the biofuel crops because the demand for biofuel inputs such as corn, soybeans and other grains results in higher prices of these grains. Diffenbaugh et al. [13] study observe that coupled with current climate conditions, energy policies and energy market integration, increases the US's corn price significantly. Hausman et al. [14] study predicts a 33% increase in corn price, Chakravorty and Roberts et al. [15,16] studies suggest 20–30% increase in the food prices by year 2020. Mitchell [7] study project a 70% increase in food prices and Lipsky [17] study predict a 70% increase in maize and 40% increase in soybean prices.

Using time series analysis, Algieri [18] finds that oil and ethanol futures returns have a significant influence on corn, wheat, sugar and soybeans prices. The study concludes that energy markets can increase the fluctuation of agricultural markets and suggests a moderate use of policies aimed at subsidising first-generation biofuels. The need for transition to advanced biofuels, with less implication for competition with food markets and GHG impacts of land use changes, is also pointed out by Linares et al. [19].

The estimates of these studies differ widely due to different data sets, time periods, types of products and the methodology they have used¹. For instance, Condon et al. [21] study examined several published studies (between 2007–2014) focused on the U.S. corn ethanol policy and corn prices, they observed that prices varies from nil to over 80%. Their meta-analysis attributes much of these price differences to modelling framework, projection year, inclusion of ethanol co-products, and biofuel production from other feedstocks. They also estimate a 3% to 4% increase in corn price as a consequence of one billion gallon expansion of the US corn ethanol mandate in 2015 and a slight variation of price changes in future years.

However, to understand the biofuel market better, it is important to study the trends and mandates of the biofuels in the economy-wide context. This paper focuses on the recent trends of biofuel production and analyse the prices of biofuel crops. It also analyses the prices of other crops and returns to biofuel production for the period 2012–2020. We do this in relation to the biofuel mandates of the three most important biofuel markets: Brazil, the EU and USA. In order to account for economy-wide effects, the analysis is carried out by using the Global Trade Analysis Project Bio Fuels (GTAP-BIO), a computable general equilibrium model to analyse the trends and polices of the biofuels in these markets under different instruments and under volatility in supply due to weather and other factors. The model was calibrated for the period 2007–2012, during which period output of biofuel production in these three regions increased by 54%.

The paper is organized as follows. The next section lays out the GTAP-BIO model and the key assumptions made. Section 3 gives the results for the baseline projections to 2020 and sensitivity of the results to the key parameters. Section 4 looks at the impacts of volatility in the supply of biofuel crops on prices and different ways in which these impacts can be addressed—by changes the mandate or by allowing a waiver. Lastly Section 5 offers some conclusions on how the negative impacts of biofuel mandates on prices may be addressed in the coming years.

2. Literature

Due to the rise in international oil prices and domestic energy security, several countries have recognized the biofuel potential and implemented several mandates to reduce the dependence on the fossil fuel. In the literature, several studies have analyzed biofuel mandates and debated largely on the trade-offs between food, feedstock, and fuels and their impact on agricultural markets [22]. Given the size of the biofuel market, studies focused on the biofuel policies implemented in US, EU and Brazil [9–13,16,23–26]. Hertel et al. [23] study examined the linkages between energy and agriculture markets in US. The study found a high positive correlation between oil prices and corn prices. The study also observed that US's ethanol production has increased 66% due to higher oil prices for the period 2001–2006. The study findings reveal that the combination of existing biofuel mandates and high energy prices, will increase the crop feedstocks in biofuel production. de Gorter and Just [27] analysed that the combination of biofuel mandates and tax credits shifts the supply curve of the biofuel upward, they argue that mandating biofuel be blend with gasoline increases the fuel prices that result in to increase of the biofuel production.

Roberts and Schlenker [15] studied the impacts of US biofuel mandates on the world food stocks. Their study reveals that ethanol production has increased in the period 2009–2011 is due to

¹ See [8] and [20] studies for the systematic differences between partial and general equilibrium models.

the combine effect of the high oil prices, subsidies and import restrictions of the ethanol. Further the study states 2009 US Renewable Fuel Standards policy was the instrumental in growth of US corn production and diversions of five% of the world calorific production.

Chakravorty et al. [16] study examine the long run impacts of US and EU biofuel mandates. The study argue that energy policies have direct impact on the food prices but that the increase in food prices will lead to increased efficiency in agriculture activities such as better irrigation, seed and other agriculture related inputs. Hunsberger et al. [28] study examined the impacts of biofuel mandates on livelihood, equity and food security, the study argues that expansion of biofuel production can lower food security via. Higher food prices and changes in the land use of food crops.

Adusumilli et al. [24] reviewed the implication of US biofuel mandates on the economy and environmental issues. The study reveals that the existing polices in US encourages the biofuel production, and it will have negative impact on the availability of land for crops and water resources. Increasing the biofuel production in US will increase the food prices and it will have direct impact on the food security and affordability. Jaiswal et al. [25] also argued that, Brazilian polices and other demand on land have influenced the sugarcane production. The demand for ethanol, increases the demand for sugar cane, new ethanol plants and road connectivity to the plant, these factors increases the pressure on available land for other food crops. On the economic side, Faclone et al. [26] study discusses the design of the effective policy mixes for the sustainable energy transitions. They have examined the impact of the economic crisis on biofuel market in Italy under two alternative scenarios. In one scenario, they have observed how biofuel production changes with economic crisis. Their study reveals that recent economic crisis in European region has affected the sustainable energy transition, but they argue that tax reliefs and subsidies will encourage the advancement of the biofuel production in Europe.

3. The model

For the analysis, we used GTAP-BIO database in which Taheripour et al. [29] has introduced three biofuel commodities (ethanol from food grains, ethanol from sugar cane and biodiesel from oilseeds) into the GTAP database. The database has 28 industries, 33 commodities and 18 regions, with these biofuel by-products have also been introduced in the database, specifically DDGS (Dry Distillers Grains with Solubles) from coarse grain ethanol and biodiesel by-products (BDBP) such as soya and oilseed meals. The GTAP-BIO model includes demand for biofuel consumption in two forms: as an additive to gasoline and as a source of energy. The demand for ethanol as a fuel additive is not price responsive and moves together with the aggregate demand for liquid fuels.

Further, Hertel et al. [9] introduced the constant elasticity of substitution (CES-type) amongst liquid fuel products consumed (σ). This measures the change in the intensity of ethanol use in total liquid fuels in response to a change in the relative price of ethanol.

$$\sigma = \frac{(qe-q)}{(p-pe)} = -\frac{(qe-q)}{(pe-p)} \quad (1)$$

Equation 1 has taken from [9], where represents σ the elasticity of substitution, qe is the percent age change demand for energy substitute i.e., ethanol/biodiesel, q is the percent age change in aggregated demand for liquid fuels. The price ratio, PE/P , provides the price of ethanol relative to the composite price index of all energy products consumed by the household, the percent age change

of the price ratio can be taken as $(pe - p)$, which is the difference of two percent age changes. When we pre-multiplied with σ , it provides the price-sensitiveness of the households change in demand for the energy substitute [9]. Further, Eq 1 provides that a larger the elasticity of substitution means higher the ethanol intensity as the price of ethanol falls compare to that of other liquid fuels.

Rearranging Eq 1 provides the final demand of the energy substitute. Higher the price of the composite, higher the demand for energy substitute.

$$qe = q - \sigma(pe - p) \quad (2)$$

The ethanol industry sells into two domestic market segments: in the first market segment, ethanol is used as a gasoline additive, in strict proportion to total gasoline production. The second segment of the market is for ethanol as an energy substitute. In contrast to the additive market, the demand in this market is price sensitive, with ethanol's market share depending on its price, relative to refined petroleum². For ease of exposition, and to be consistent with the general equilibrium model, we will think of the additive demand as a derived demand by the petroleum refinery sector, and the energy substitution as being undertaken by consumers. The demand for both market segments together can be represented as the final demand for ethanol (D_e) and biodiesel (D_{bd}).

We can obtain final demand of ethanol (D_e) by rearranging Eq 1:

$$D_e = q - \sigma_{ELIHBOOIL} * (p_e - p) \quad (3)$$

Similarly, we can obtain the final demand of biodiesel (D_{bd}):

$$D_{bd} = q - \sigma_{ELIBIOD} * (p_{bd} - p) \quad (4)$$

$(p_e - p)$ and $(p_{bd} - p)$ represents the price share of ethanol and biodiesel relative to a composite energy price index for all the commodities consumed by households. $\sigma_{ELIHBOOIL}$ and $\sigma_{ELIBIOD}$ are the elasticities of substitution between liquid fuels. Eq 3 provides the demand for ethanol in the regions where ethanol is used as biofuel i.e., US and Brazil, whereas Eq 4 provides EU's demand for the biodiesel. The share of ethanol/gasoline (blend) and biodiesel have been assumed as constant and, do not depend on the oil price. Thus the percent age change in demand for ethanol/biodiesel depends on the change in aggregate demand for liquid fuels and on changes in the intensity of ethanol/biodiesel use in liquid fuels, governed by a CES.

3.1. Biofuel and biodiesel production

In the GTAP-BIO economy model, ethanol output is determined by the following factors: i) the input/output ratio which indicates the blend for fuel; ii) the price of composite liquid fuels; iii) the prices of feedstocks and iv) the level of ad-valorem subsidy for sustaining ethanol production. These subsidies are of course revenue neutral. The supplies of ethanol and biodiesel in the GTAP model are based on assuming profit maximization and a zero profit condition (i.e., competition ensures that firms do not make super normal profits). The model assumes that producer selects the output level

² Demand for biofuels is also affected by the penetration of electric vehicles. As this increases the demand for petroleum will fall, as will its price, making production of biofuels less attractive. This effect has not been modelled directly; one could argue that it is likely to be more significant further in the future than we consider in this paper.

for each sector based on these conditions. The zero profit condition provides the following relationship (the equations are obtained from [29]).

$$ps_j = \sum_i \theta_i pf_{ij} \quad (5)$$

where ps_j the percent age change in price of output sector j i.e., ethanol or biodiesel, θ_i is the share of input i in total production cost of commodity j , and pf_{ij} is the percent age change in price of input paid by sector j .

The fuel blend (which we understand as the combination of ethanol and fossil gasoline) is not taken into account explicitly by GTAP model in order to simulate national mandates. A common strategy adopted in work in this area is to treat the blends as exogenous [23]. Since we cannot directly change blend options or renewable prices explicitly (they have to be kept endogenous), the only way to vary the fuel blend is by varying the biofuel subsidies so as to get the aggregate blend we want. This subsidy is introduced in the supply equation for the producers of biofuels. In the case of an exogenous shock (e.g., a rise or fall in yields of primary products) the model is recalibrated with a subsidy level that generates the required fuel blend. In Eq 4 the subsidy would modify the equation to:

$$ps_j(1 + \varphi_j) = \sum_i \theta_i pf_{ij} \quad (6)$$

where φ is the subsidy given as a percent age of the price of the biofuel.

This method of modelling the fuel blend has been used by others to see how changing the blend affects the price (see e.g., [10,29,30]). Accordingly, we treat the mandates as exogenous shocks by simulating a subsidy policy. In GTAP language, we swap the total production of the bio-commodity in a given region with the relative taxation to simulate a subsidy. As a result, subsidies are treated as endogenous (see e.g., [10,29,30]) and the biofuel output, now exogenous, can be shocked to match a given target level. For instance, in the case of ethanol in EU, the main shocks are written as:

$$\text{Swap } q_o(\text{"Ethanol", "EU"}) = \text{tpd}(\text{"Ethanol", "EU"}) \quad (7)$$

$$\text{Shock } q_o(\text{"Ethanol", "EU"}) = X \quad (8)$$

where X indicates the level of shock (in percent age), q_o is the biofuel output, tpd is the values of bilateral import taxes. We also imposed a revenue-neutral subsidy with the following shock:

$$\text{Swap } del_taxrpbio(\text{"EU"}) = \text{tpbio}(\text{"EU"}) \quad (9)$$

which guarantees that the subsidy is financed by additional taxes for biofuel consumption.

An important role is played by the elasticity of substitution between biofuels and petroleum products ($\sigma_{ELIHBOIL}$), which we observed from the empirical estimation by Birur et al. [31]. The values of this parameter vary across the three modelled regions (US, Brazil and EU27) and reflect different country-specific characteristics. The values are USA = 3.95, Brazil = 1.35 and EU = 1.65. For all of the other countries the value is 2, which approximates an average value. In particular, the model tells that lower elasticity of substitution in Brazil has higher penetration of the biofuel market, it also tells that, the higher fuel prices in Brazil has limited scope to expand the biofuel use compare to that of US and EU. The higher US elasticity compared to the EU elasticity reflects the higher growth of EU renewable fuels during the estimation period (2001–2006).

4. Model simulation

4.1. Historical validation

In order to provide an ex-ante simulation of the effects of mandates for biofuels, we firstly need to build an up-to-date baseline that reflects the economy and biofuel sector dynamics from 2004 (the starting year of our dataset) to 2012. We followed a common approach for CGE models by shocking the drivers of growth that are exogenous to the model, namely population, labor force (skilled and unskilled labour) and productivity to allow real GDP growth rates and other endogenous variables to reproduce historical paths for the 2004–2012 period. The historical data for macro variables derive from the combination of several sources. Namely, population is given by UN Statistics, GDP derives from the OECD and IMF Statistics, labour force, including both skilled and unskilled workers, derive from ILO and GTAP macro projections provided by Chappuis et al. [32]. Our baseline also reproduces growth level in biofuel sector by introducing revenue-neutral subsidizing policies in EU, USA and Brazil and according to the methodology described in 2.1. The historical matching of the biofuel sector reproduced by the model is validated by using the OECD-FAO [33] projections for agricultural yields over the period 2004–2012.

4.2. Ex-ante simulation (2013–2019)

For our ex ante simulations we run the model up to 2019 by imposing different policy targets for the biofuel sector and leaving unchanged the economy at 2012 (a similar approach is followed in [34]). As stressed in [9], this approach allows for a static comparison of the biofuel economy at different periods (2013,..., 2019) with the global economy unchanged, while reducing the information required by our model and the model convergence. Yields for coarse grains, oil seeds and sugar crops are also generally expected to go up (the exception is sugar crops in Brazil). From the model simulation, we observed changes in prices for all 35 sectors (which includes agriculture, fossils etc.) between 2012 and 2020 for USA, EU27 and Brazil (see Table 1)³.

The model predicts the fall in prices of coarse grains of between 8% and 14%; of oil seeds of between 15% and 20%; of sugar crops of between 7% and 21%. The USA is the region with the biggest fall in prices, followed by EU and Brazil (Table 1). As expected these declines are feed through to lower prices for biofuels. We also can see a slight drop in the price of ethanol from sugar (Ethanol 2) and a larger drop in the price of ethanol from grains (Ethanol 1) and biodiesel from oilseeds. The price of DDGS declines 10–13% in the USA and EU27 but rises significantly in Brazil.

At the same time, the biofuel output is expected to grow in the three selected regions from around 78 billion liters in 2012 to 145 billion liters by 2020, an increase of 86% [33]. In EU, ethanol from grains is expected to grow from 2.8 billion liters to 10.9 billion liters, an increase of 290%. Whereas biodiesel in the EU is expected to grow slowly, between 2012–2020 it is expected to

³ The model actually also calculates annual changes for all 19 regions but to keep the presentation manageable only a limited number of the model results are shown. The detailed outputs are available on request.

increase by 60% (7.5 billion liters to 11.9 billion liters). There will be a significant increase in ethanol from sugarcane in Brazil: from 15.3 billion liters to 43.7 billion liters, an increase of 186%⁴.

Table 1. Price changes for model sectors: 2012–2020 (%).

| | USA | EU27 | Brazil | | USA | EU27 | Brazil |
|----------------|--------|--------|--------|-----------------|--------|--------|--------|
| Paddy_Rice | -9.73 | -4.15 | -8.83 | Oth. Prim. Sect | 0.55 | 0.95 | 1.16 |
| Wheat | -3.80 | -5.54 | -4.45 | Ethanol 2 | 0.08 | 0.28 | -2.10 |
| Coarse. Grains | -14.48 | -11.66 | -8.47 | Biodiesel | -3.42 | -6.79 | -11.70 |
| Oilseeds | -20.05 | -16.07 | -15.53 | Coal | 0.57 | 0.88 | 0.73 |
| Sugar_Crop | -20.50 | -9.08 | -6.77 | Oil | -0.35 | -0.64 | -2.07 |
| Other Agri. | -8.70 | -6.99 | -6.78 | Gas | 0.14 | 0.02 | 1.14 |
| Forestry | -4.96 | -5.23 | -4.54 | Oil Products | -0.46 | 0.08 | 0.11 |
| Dairy_Farms | -3.71 | -5.16 | -0.47 | Electricity | 0.27 | 0.38 | 1.51 |
| Ruminant | -3.15 | -4.94 | -0.37 | En. Int. Ind. | 0.19 | 0.34 | 0.63 |
| Non Ruminant | -6.05 | -4.42 | -0.64 | Oth. Ind. Se. | 0.31 | 0.36 | 1.24 |
| Proc. Dairy | -1.29 | -1.92 | 0.14 | NTrdServices | 0.18 | 0.46 | 1.55 |
| Proc. Rum | -1.72 | -2.06 | 0.07 | Pasture crop | 4.03 | -2.55 | 4.00 |
| Proc. NonRum | -2.14 | -1.92 | -0.17 | Ethanol 1 | -4.51 | -0.69 | -4.93 |
| Rveg. Oil | -2.04 | -1.54 | -4.06 | DDGS | -13.19 | -10.59 | - |
| Bev. Sug | -1.30 | -1.11 | -3.30 | Cveg_Oil 1 | -3.91 | -7.91 | -7.26 |
| Proc. Rice | -0.96 | -1.28 | -4.02 | VOBP | -24.76 | -22.47 | -16.56 |
| Proc. Food | -0.95 | -1.48 | -1.78 | CGDS | 0.32 | 0.35 | 1.09 |
| Proc. Feed | -7.35 | -5.76 | -9.82 | | | | |

Note: Ruminant: cattle & ruminant meat production, Proc.: processed, NTrdServices: Services generating Non CO₂ Emissions, En. Int. Ind.: Energy intensive industries, Oth. Ind. Se.: Other industries and services, Oth. Prim. Sect: Other primary products, Ethanol 1: Ethanol produced from grains, Ethanol 2: Ethanol produced from sugarcane, DDGS: Dried distillers grains with solubles, Cveg_Oil 1: crude Vegetable oils and fats, VOBP: Soybean meals, CGDS: Agg. capital goods.

As a result of the changes in prices (big declines in the prices of feedstocks but much smaller declines in the prices of biofuels), the returns to biofuel producers are expected to increase significantly over the period 2012–2020. In determining the returns to biofuels it is assumed that producers determine output to maximize profits as a function of the prices of inputs and outputs. This fixes the supply side of the market for these products.

The demand side is partly also determined by the prices but also by regulations on how much biofuel is to be mixed with fossil fuels in the mix for transportation. The projections to 2020 assume that current regulations in the respective countries will continue to hold over that period. If prices of feedstocks are high and domestic production of biofuels is not enough to meet the mandated requirement, the demand side of the market is met through imports.

⁴ As stated, these projections are taken from the FAO/OECD. We checked the figures against another source, namely the EU prospective study (http://ec.europa.eu/agriculture/markets-and-prices/medium-term-outlook/2013/tables_en.xls).

4.3. Sensitivity analysis

For the sensitivity analysis we look at the different possible variations: a) variations in the elasticity of substitution between fossil fuels and biofuels; b) variations in the elasticity of substitution between capital and energy; c) variations in the elasticity of substitution between coal and non-coal energy; d) variations in the Armington⁵ elasticity between imported and domestic versions of a given commodity. In the case of (a) to (d) we consider values of the elasticities that are 30% higher and 30% lower than in the Base Case. Table 2 provides the results of the sensitivity analysis.

The sensitivity analysis is performed for the case where yields of the main feedstocks for biofuels increase as predicted by the FAO assessment for the period 2012–2014. The sensitivity tests were only done for these two years, comparing the changes in prices against those obtained with the yields of primary products as given in the baseline.

The sensitivity analysis indicates that a higher elasticity of substitution between fossil fuel and biofuels results in a greater demand for biofuels when yields of feedstocks rise and their prices fall. Hence the price of biofuels falls less due to an increase in feedstocks yields than in the Base Case when the elasticity is higher and conversely it falls more than the Base case when the elasticity is lower. By the same token the higher elasticity of substitution results in greater demand for feedstocks and the resulting price fall for these feedstocks is less than it is in the Base Case (i.e., prices rise relative to the Base Case). From the Table 2 we can observe that, with 30% higher elasticity of substitution between fossil fuels and biofuels, the prices of grains are expected to increase by 8%, 2.2% and 2.7% in USA, EU and Brazil respectively. Whereas, biodiesel prices increases by 13%, 9.3% and 2.9% in the respective regions. The effects for rises and falls in the elasticity of substitution appear to be quite symmetric.

In the case of capital and energy, a higher elasticity of substitution between capital and energy translates into a greater ability to use all energy (including biofuel based) when yields on feedstocks are raised. The impact, however of variations in the range considered are negligible. The results reported in the Table 2 suggests that 30% higher elasticity between coal and non-coal energies has very small impact on the prices of grains, oil seeds, sugar crops and biodiesel. A similar impact arises when coal and non-coal energy are more substitutable. In this case the demand for biofuels as a type of non-coal energy increases and prices rise a little. Equally when the elasticity between the two types of fuels is less than in the Base Case the demand for biofuels declines and the price increases are less than in the Base Case. The impacts, however, are very small for variations considered.

A bigger effect on prices is observed when the Armington elasticities are raised relative to the Base Case. A higher elasticity implies that any differences in prices of feedstocks or biofuels results in more trade for the inputs and/or the outputs of the biofuel sector. This makes the whole sector more sensitive to relative changes in yields and prices within regions. The result is large increases in the prices of both inputs and outputs (including DDGS). Equally, with lower values for these elasticities the impacts on prices is correspondingly smaller. Again the effects generated by the model appear to be quite symmetric for the rises and falls in these elasticities.

⁵ Armington elasticity governs the level of substitution between domestic and imported goods. In CGE models this elasticity is a key parameter able to substantially affect the model results. See [35] and [36] for further details.

Table 2. Sensitivity analysis for elasticities.

| % Change in Prices Relative to Base Case | | | | | | | |
|--|---------|--------|---------|--|--------|--------|--------|
| | USA | EU | Brazil | | USA | EU | Brazil |
| If Elasticity of Substitution Between Fossil Fuels and Biofuels is 30% Higher: | | | | If Elasticity of Substitution Between Coal and Non-Coal Energy is 30% Higher | | | |
| Cr. Grains | 8.00% | 2.20% | 2.70% | Cr. Grains | 0.60% | 0.00% | 0.10% |
| Oil Seeds | 4.70% | 5.70% | 4.00% | Oil Seeds | 0.10% | 0.00% | 0.10% |
| Sugar Crop | 5.10% | 1.80% | 10.20% | Sugar Crop | 0.30% | 0.00% | 0.10% |
| Ethanol 2 | 0.10% | 0.20% | 4.10% | Ethanol 2 | 0.00% | 0.00% | 0.00% |
| Ethanol 1 | 4.30% | 0.50% | 0.90% | Ethanol 1 | 0.50% | 0.00% | 0.00% |
| Biodiesel | 13.10% | 9.30% | 2.90% | Biodiesel | 0.10% | 0.00% | 0.00% |
| DDGS | 2.60% | 2.50% | 3.20% | DDGS | 0.50% | 0.20% | 0.20% |
| If Elasticity of Substitution Between Fossil Fuels and Biofuels is 30% Lower: | | | | If Elasticity of Substitution Between Coal and Non-Coal Energy is 30% Lower | | | |
| Cr. Grains | -8.00% | -2.20% | -2.70% | Cr. Grains | -0.60% | 0.00% | -0.10% |
| Oil Seeds | -4.70% | -5.70% | -4.00% | Oil Seeds | -0.10% | 0.00% | -0.10% |
| Sugar Crop | -5.10% | -1.80% | -10.20% | Sugar Crop | -0.30% | 0.00% | -0.10% |
| Ethanol 2 | -0.10% | -0.20% | -4.10% | Ethanol 2 | 0.00% | 0.00% | 0.00% |
| Ethanol 1 | -4.30% | -0.50% | -0.90% | Ethanol 1 | -0.50% | 0.00% | 0.00% |
| Biodiesel | -13.10% | -9.30% | -2.90% | Biodiesel | -0.10% | 0.00% | 0.00% |
| DDGS | -2.60% | -2.50% | -3.20% | DDGS | -0.50% | -0.20% | -0.20% |
| If Elasticity of Substitution Between Capital and Energy is 30% Higher | | | | If Armington Elasticity Between Domestic & Imported allocation is 30% Higher | | | |
| Cr. Grains | 0.00% | 0.00% | 0.00% | Cr. Grains | 8.30% | 4.50% | 5.70% |
| Oil Seeds | 0.00% | 0.00% | 0.00% | Oil Seeds | 23.40% | 3.20% | 18.50% |
| Sugar Crop | 0.00% | 0.00% | 0.00% | Sugar Crop | 9.00% | 3.00% | 9.40% |
| Ethanol 2 | 0.00% | 0.00% | 0.00% | Ethanol 2 | 0.20% | 0.20% | 3.70% |
| Ethanol 1 | 0.00% | 0.00% | 0.00% | Ethanol 1 | 1.60% | 3.60% | 3.10% |
| Biodiesel | 0.00% | 0.00% | 0.00% | Biodiesel | 4.20% | 1.20% | 13.50% |
| DDGS | 0.00% | 0.00% | 0.00% | DDGS | 6.80% | 5.90% | 4.90% |
| If Elasticity of Substitution Between Capital and Energy is 30% Lower | | | | If Armington Elasticity Between Domestic & Imported allocation is 30% Lower | | | |
| Cr. Grains | 0.00% | 0.00% | 0.00% | Cr. Grains | 8.30% | 4.50% | 5.70% |
| Oil Seeds | 0.00% | 0.00% | 0.00% | Oil Seeds | 23.40% | 3.20% | 18.50% |
| Sugar Crop | 0.00% | 0.00% | 0.00% | Sugar Crop | 9.00% | 3.00% | 9.40% |
| Ethanol 2 | 0.00% | 0.00% | 0.00% | Ethanol 2 | 0.20% | 0.20% | 3.70% |
| Ethanol 1 | 0.00% | 0.00% | 0.00% | Ethanol 1 | 1.60% | 3.60% | 3.10% |
| Biodiesel | 0.00% | 0.00% | 0.00% | Biodiesel | 4.20% | 1.20% | 13.50% |
| DDGS | 0.00% | 0.00% | 0.00% | DDGS | 6.80% | 5.90% | 4.90% |

For the price of crude oil that is different from the baseline we took projections as given by the US Energy Information Administration (EIA) [1] for the period 2014–2020. To test the impacts simulations were carried out for two years: 2014, 2020 (Table 3). The overall impact of the crude oil on the biofuel demand is ambiguous. Whenever they are substitutes, a lower crude oil price increases

the demand for oil based products and reduces that for some biofuels but increases the biofuels to the extent they are complements.

However, there are other effects of oil prices changes in a CGE model and the combination of these with the direct effects mentioned above are difficult to predict. If there is a decline in the demand for substitutes this should also feed through to a lower demand for feedstocks, which then would also fall in price. The expected changes indicate a rise in the price of biofuels and feedstocks when oil prices rise (relative to the baseline), but they do not always indicate a fall in these prices relative to the baseline when oil prices fall (Table 3).

Table 3. Impacts of lower and higher oil prices (% change).

| Coarse Grains | | | Ethanol 2 | | |
|------------------|------|------|------------------|------|------|
| | 2014 | 2020 | | 2014 | 2020 |
| Baseline | -3.3 | -3.1 | Baseline | 0.1 | 0.2 |
| Oil Price Lower | -0.6 | -5.4 | Oil Price Lower | -2.2 | -1.4 |
| Oil Price Higher | 0.5 | 9 | Oil Price Higher | 1.2 | 2.4 |
| Oil Seeds | | | Ethanol 1 | | |
| | 2014 | 2020 | | 2014 | 2020 |
| Baseline | -6.3 | -4.2 | Baseline | -0.2 | 0.3 |
| Oil Price Lower | -2.6 | -2.9 | Oil Price Lower | -0.5 | -1.6 |
| Oil Price Higher | 1.7 | 4.8 | Oil Price Higher | 0.4 | 2.8 |
| Sugar Crop | | | Biodiesel | | |
| | 2014 | 2020 | | 2014 | 2020 |
| Baseline | -2 | -3.9 | Baseline | -2.9 | -3.4 |
| Oil Price Lower | -0.7 | -3.7 | Oil Price Lower | -4.8 | -5 |
| Oil Price Higher | 0.5 | 6.2 | Oil Price Higher | 2.7 | 8.4 |

5. Impacts of volatility in the supply of biofuels

5.1. Impacts of changes in yields

The estimated changes in yields between 2012 and 2020 as given in [33] do not take account of possible fluctuations on account of climatic and other factors. In the past such influences have been responsible for variations in yields relative to the mean of up to 19% in Europe and the USA and more than 25% in Brazil⁶. The impacts of these variations on prices of agricultural products can be considerable, as we have seen in the data from the markets for 2008 and 2012.

In order to see the implications of possible future fluctuations in yields four artificial scenarios have been constructed for the period 2013–2020, with variations in yields that reflect historic experiences but do not attempt to replicate them exactly. Table 4 provides the description of four different variations that are considered for the analysis.

⁶ Based on data from 1995 to 2012, taken from FAO.

Table 4. Future fluctuations in terms of possible Variants.

| Future fluctuations in terms of possible Variants | |
|---|--|
| Variant I | Two years with big declines sandwiched by two years of modest increases in yields |
| Variant II | Two initial years with high yield increases sandwiched by two years with lower yield changes |
| Variant III | Alternative years with positive and negative yield changes |
| Variant IV | Three years with high yields followed by three years with lower yields and final year with high yields |

The GTAP-BIO model was run with these changes to see the impact on prices, trade flows and returns to biofuel producers. In this study we focused only the changes for the EU27. We have observed that declines in yields feed through significantly to increases in the prices of coarse grains, oilseeds and sugar crops and vice-versa (see Table 5). The impact of changes in yields is greater on price in the case of sugar crops, followed by grains and oilseeds. The results tell us that for coarse grains a one percent increase in yield results in a fall in the price of between 1.1 (Variant IV) to 2.4% (Variant III), in case of oil seeds the fall will be between 1.2 (Variant IV) and 1.8% (Variant I) and for sugar crops, it will be in between 1.3 (Variant IV) and 2.9% (Variant I).

The impact of the changes in yields on the prices of biofuels is very small. This must be the result of the fact that biofuel output process is linked to the price of petroleum products and cannot respond to the increase in the price of feedstocks. The consequence of these two phenomena is that when yields decline and prices of feedstocks rise the returns to biofuels decline very sharply and conversely when the price of feedstocks fall, the returns to biofuels increase sharply.

We further investigated the impacts of a higher elasticity of substitution on the price changes for feedstocks and biofuels when future yields change more dramatically than in the baseline. The four variants described above were examined for a selection of cases to allow for years when yields on feedstocks are higher or lower than the baseline. As in the Base Case the price falls are reduced with a higher elasticity of substitution between fossil and biofuels when there is an increase in the supply of feedstocks and the prices rises are reduced when there is a decline in the supply. With the shocks imposed in the four variants, the reductions vary by variant but the results are broadly consistent with those of baseline projections (see Table 2) i.e., the percent age reduction in the price change due to a 30% higher elasticity in EU27 was: 2.2% (Coarse Grains); 5.7% (oilseeds) and 1.8% (Sugar Crops).

Table 5. Changes in prices in relation to changes in yields in EU27.

| | | Change in yield (%) | | | |
|---------------------|---------------|---------------------|------------|-------------|------------|
| | | Variant I | Variant II | Variant III | Variant IV |
| Change in price (%) | Coarse Grains | -1.95 | -1.37 | -2.38 | -1.11 |
| | Oil Seeds | -1.78 | -1.51 | -1.74 | -1.15 |
| | Sugar Crop | -2.85 | -1.5 | -2.5 | -1.33 |

5.2. Impacts on changes in mandates when yields are low

In this section we consider the impacts of the volatility analyzed in the previous section when mandates for the share of petroleum products that must be made up of biofuels are changed to compensate for the low yields. It has been argued that when yields decline for climatic and other reasons the prices of feedstocks rise exceptionally because of the demand from biofuels which is

predetermined by the requirement that a given percent age of gasoline and diesel is made up of biofuels.

Formal mandates for biofuels are present in Brazil, the EU, USA and some other countries. It is difficult to get information on all the mandates and to convert them into production targets for the regions in the model. Hence, in order to estimate the impacts of changes in formal and/or informal regulations we consider the case where Brazil, the EU and the USA have a 35% lower production of biofuels in the different years under the four variants.

All these variants have yields exhibiting considerable volatility over the period analyzed. The results are shown only for prices of coarse grains, sugar crops and oil seeds in the EU 27. Furthermore, we have only analyzed the changes for first four years (2013–2016). This is because the model reliability appears to decline the further we go from the last year of historic data (2012) and as we impose further shocks on the system⁷. A change in the mandate is a change in the demand side of the market for biofuels. When there is a reduction of, for example, 35% then demand is lowered by this amount and prices of feedstocks fall. Table 6 provides the feedstock prices with and without a 35% reduction in biofuel production.

Producers react by adjusting output to the change in prices and the model calculates the new equilibrium with the lower demand. Since we cannot model the transport sector explicitly the change in the mandate can only be evaluated in terms of the impact of a reduction in demand for biofuels of a given amount. In practice, such a change would need to be made operational through a change in the fuel mix regulations. For each variant we see that when prices fall as a result of higher yields, the fall is greater when demand for biofuels is reduced by 35%. Equally when prices rise as a result of lower yields the rise is less when biofuel demand is reduced by 35%.

We have examined the price fall/rise by comparing the percent changes in prices with and without the mandate. In these lines, for coarse grains, the rise in prices is reduced by about one percent in Variants I, III and IV and reduced by 1 to 6% in case of Variant II. For sugar crops the rise in prices is reduced by 1–5% across the Variants. For biodiesel crops the results are somewhat different. Under Variant II the price drop is bigger in some years—about 5–8% and in Variants III and IV there are years when the price drop is smaller with the mandate.

Our results show that shortages in feedstocks can be affected less by a reduction in the mandate than increases in feedstocks. Modelling of increases in mandates (not shown here) confirm the above results. An increase in production of 35% in the target for Brazil, EU and USA would raise prices, depending on what conditions prevail in the feedstock market. If prices are raised as a result of shortages then the higher demand will raise prices by the ranges stated in above (most for biodiesel, next for sugar crops and least for coarse grains). On the other hand, if market conditions results in a general fall in prices, the fall will be made smaller due to the increased demand for biofuel production. The impact will be most for sugar crops, followed by biodiesel and coarse grains.

Further the analysis was done to compare the price change of EU 27 within all three regions against EU alone. The mandate impacts are much smaller in the EU 27 region compared to all the three regions. In case of EU 27 alone, for coarse grain, a one percent increase in price would reduce

⁷ Our dataset starts from 2007. We calibrate the model based on historical trends to 2011 and simulate scenarios from 2012. Given the linear approximation of this static model, if we impose too high shocks the model convergence and the reliability of results is not guaranteed.

Table 6. Changes in prices of biofuel feedstocks in EU with and without a 35% reduction biofuel production in all three regions.

| Variant I | 2013 | 2014 | 2015 | 2016 | Variant II | 2013 | 2014 | 2015 | 2016 |
|---|-------|--------|--------|-------|---|-------|--------|--------|-------|
| <i>Coarse Grains</i> | | | | | <i>Coarse Grains</i> | | | | |
| Change in Yield (%) | 1.41 | -19.56 | -14.46 | 1.09 | Change in Yield (%) | 1.41 | 13.56 | 16.64 | -6.69 |
| Δ Price with No Ethanol Mandate (%): | -2.09 | 40.94 | 21.82 | -3.96 | Δ Price with No Ethanol Mandate (%): | -2.09 | -16.10 | -21.20 | 12.00 |
| Δ Price with 35% Less Ethanol Mandate (%) | -2.91 | 40.42 | 20.66 | -4.99 | Δ Price with 35% Less Ethanol Mandate (%) | -3.01 | -17.16 | -26.71 | 11.16 |
| Impact of 35% Mandate | -0.82 | -0.52 | -1.16 | -1.03 | Impact of 35% Mandate | -0.92 | -1.06 | -5.51 | -0.84 |
| <i>Sugar Crops</i> | | | | | <i>Sugar Crops</i> | | | | |
| Change in Yield (%) | 0.46 | -20.32 | -13.22 | 2.56 | Change in Yield (%) | 0.46 | 12.49 | 18.34 | -5.33 |
| Δ Price with No Ethanol Mandate (%): | -1.40 | 62.95 | 29.76 | -5.31 | Δ Price with No Ethanol Mandate (%): | -1.41 | -17.50 | -23.80 | 12.80 |
| Δ Price with 35% Less Ethanol Mandate (%) | -2.31 | 61.66 | 28.29 | -6.91 | Δ Price with 35% Less Ethanol Mandate (%) | -2.41 | -18.56 | -26.79 | 11.39 |
| Impact of 35% Mandate | -0.91 | -1.29 | -1.47 | -1.60 | Impact of 35% Mandate | -1.00 | -1.06 | -2.99 | -1.41 |
| <i>Oil Seeds</i> | | | | | <i>Oil Seeds</i> | | | | |
| Change in Yield | 2.89 | -18.40 | -12.90 | 2.93 | Change in Yield | 2.89 | 15.20 | 18.77 | -4.99 |
| Δ Price with No Biodiesel Mandate (%): | -2.96 | 38.62 | 17.07 | -3.54 | Δ Price with No Biodiesel Mandate (%): | -2.97 | -17.10 | -28.20 | 9.90 |
| Δ Price with 35% Less Biodiesel Mandate (%) | -3.96 | 34.30 | 13.35 | -4.74 | Δ Price with 35% Less Biodiesel Mandate (%) | -4.31 | -22.18 | -36.58 | 8.22 |
| Impact of 35% Mandate | -1.00 | -4.32 | -3.72 | -1.20 | Impact of 35% Mandate | -1.34 | -5.08 | -8.38 | -1.68 |
| Variant III | 2013 | 2014 | 2015 | 2016 | Variant IV | 2013 | 2014 | 2015 | 2016 |
| <i>Coarse Grains</i> | | | | | <i>Coarse Grains</i> | | | | |
| Change in Yield (%) | 1.41 | -3.66 | 5.00 | -18.0 | Change in Yield (%) | 1.41 | 14.60 | 15.00 | 10.00 |
| Δ Price with No Ethanol Mandate (%): | -2.09 | 5.54 | -7.51 | 46.10 | Δ Price with No Ethanol Mandate (%): | -2.09 | -17.10 | -17.77 | -28.1 |
| Δ Price with 35% Less Ethanol Mandate (%) | -2.81 | 4.78 | -8.24 | 43.65 | Δ Price with 35% Less Ethanol Mandate (%) | -2.81 | -17.90 | -18.50 | -28.8 |
| Impact of 35% Mandate | -0.72 | -0.76 | -0.73 | -2.45 | Impact of 35% Mandate | -0.72 | -0.80 | -0.73 | -0.65 |
| <i>Sugar Crops</i> | | | | | <i>Sugar Crops</i> | | | | |
| Change in Yield (%) | 0.46 | -4.56 | 6.53 | -16.8 | Change in Yield (%) | 0.46 | 13.52 | 16.67 | 11.60 |
| Δ Price with No Ethanol Mandate (%): | -1.41 | 8.26 | -9.99 | 47.02 | Δ Price with No Ethanol Mandate (%): | -1.41 | -18.22 | -20.71 | -30.9 |
| Δ Price with 35% Less Ethanol Mandate (%) | -2.20 | 7.20 | -10.87 | 41.85 | Δ Price with 35% Less Ethanol Mandate (%) | -2.20 | -19.04 | -21.60 | -27.5 |
| Impact of 35% Mandate | -0.79 | -1.06 | -0.88 | -5.17 | Impact of 35% Mandate | -0.79 | -0.82 | -0.89 | -3.40 |
| <i>Oil Seeds</i> | | | | | <i>Oil Seeds</i> | | | | |
| Δ Price with No Biodiesel Mandate (%): | -2.97 | 4.87 | -9.28 | 30.73 | Δ Price with No Biodiesel Mandate (%): | -2.97 | -18.72 | -19.03 | -20.3 |
| Δ Price with 35% Less Biodiesel Mandate (%) | -3.44 | 0.88 | -1.68 | 25.51 | Δ Price with 35% Less Biodiesel Mandate (%) | -2.34 | -21.27 | -21.62 | -16.8 |
| Impact of 35% Mandate | -0.47 | -3.99 | 7.60 | -5.22 | Impact of 35% Mandate | 0.63 | -2.55 | -2.59 | 3.44 |

only one percent, whereas this impact was much larger in the case of all region model. A one percent fall in price due to mandate would increase the price by 13%, and for sugar crops, that would now reduce by 7 to 11%. Biofuel crops are price sensitive, a one percent increase in price would reduce by 17 to 52% in EU27 region, whereas this impact was much bigger in the case of three region model (17–82%).

5.3. Measures to reduce the impact of volatility in yields: waivers

Another policy that could be used to address, years with low yields can be given waivers so the mandate is reduced by a given percentage for the year of the low yield. In order to see the effects of waivers during period when prices of feedstocks are high, we evaluated the following cases

Table 7. Impacts of a 90% waiver for biofuel production in EU27.

| Variant I | 2014 | 2015 | Variant II | 2018 | 2019 |
|-------------------------------------|--------|--------|-------------------------------------|--------|--------|
| <i>Coarse Grains</i> | | | <i>Coarse Grains</i> | | |
| Change in Yield (%) | -19.56 | -14.46 | Change in Yield (%) | -13.27 | -13.28 |
| Δ Price with No Ethanol Waiver (%): | 40.94 | 21.82 | Δ Price with No Ethanol Waiver (%): | 72.73 | 27.09 |
| Δ Price with 90% Waiver (%) | 30.28 | 7.40 | Δ Price with 90% Waiver (%) | 19.95 | 1.55 |
| <i>Sugar Crops</i> | | | <i>Sugar Crops</i> | | |
| Change in Yield (%) | -20.32 | -13.22 | Change in Yield (%) | -15.66 | -13.33 |
| Δ Price with No Ethanol Waiver (%): | 62.95 | 29.76 | Δ Price with No Ethanol Waiver (%): | 71.68 | 10.00 |
| Δ Price with 90% Waiver (%) | 46.42 | 7.34 | Δ Price with 90% Waiver (%) | 17.87 | 4.84 |
| <i>Oil Seeds</i> | | | <i>Oil Seeds</i> | | |
| Change in Yield | -18.40 | -12.90 | Change in Yield | -12.82 | -14.46 |
| Δ Price with No Biodiesel Waiver | 38.62 | 17.07 | Δ Price with No Biodiesel Waiver | 41.69 | 3.97 |
| Δ Price with 90% Waiver (%) | 15.83 | 16.26 | Δ Price with 90% Waiver (%) | -1.51 | -13.41 |
| Variant III | 2016 | 2018 | Variant IV | 2017 | 2018 |
| <i>Coarse Grains</i> | | | <i>Coarse Grains</i> | | |
| Change in Yield (%) | -18.00 | -17.73 | Change in Yield (%) | -9.75 | -12.78 |
| Δ Price with No Ethanol Waiver (%): | 46.10 | 44.00 | Δ Price with No Ethanol Waiver (%): | 12.79 | 70.29 |
| Δ Price with 90% Waiver (%) | 17.68 | 7.98 | Δ Price with 90% Waiver (%) | -1.41 | 18.39 |
| <i>Sugar Crops</i> | | | <i>Sugar Crops</i> | | |
| Change in Yield (%) | -16.81 | -10.27 | Change in Yield (%) | -12.24 | -15.20 |
| Δ Price with No Ethanol Waiver (%): | 47.20 | 15.62 | Δ Price with No Ethanol Waiver (%): | 14.16 | 69.39 |
| Δ Price with 90% Waiver (%) | 22.51 | -0.21 | Δ Price with 90% Waiver (%) | 8.84 | 16.33 |
| <i>Oil Seeds</i> | | | <i>Oil Seeds</i> | | |
| Change in Yield | -16.39 | -7.25 | Change in Yield | -9.29 | -12.34 |
| Δ Price with No Biodiesel Waiver | 30.73 | 25.14 | Δ Price with No Biodiesel Waiver | 8.64 | 40.28 |
| Δ Price with 90% Waiver (%) | 3.53 | 11.88 | Δ Price with 90% Waiver (%) | -2.16 | -2.39 |

Note: Variant I: two years with big declines followed by two years with major increase in yields; Variant II: two initial years with high yields followed by two later years with low yields; Variant III: alternative years with high and low yields; Variant IV: three years with high yields followed by three years with lower yields and final year with high yields. Δ represents the percent age change.

compared to the baseline: Variant I: 2014 and 2015, when yields for the three feedstocks are made to fall by around 19 to 20 and 13 to 14% respectively; Variant II: 2018 and 2019, when yields for the three feedstocks are made to fall by around 13 to 15 and 13 to 14% respectively; Variant III: 2016 and 2018, when yields for the three feedstocks fell by 16 to 18 and 7 to 10% respectively; Variant IV: 2017 and 2018 when yields for the three feedstocks fell by 9 to 10 and 12 to 13% respectively. Table 7 provides the change in the prices of feedstocks with 90% waiver.

The reductions by waiver in all the cases were by 90% in each of the three regions (EU, USA and Brazil) and were imposed in the year of the fall in yields⁸. The model indicates that if a global waiver of 90% is made in the selected years then price rise for the feedstock is reduced by an amount that varies by feedstock and by year. The best way to represent the link between the two is to calculate the elasticity: the percentage reduction in price for a one percent fall in the yield of a given feedstock when a 90% waiver is introduced in the year. From the results obtained these elasticities for the EU are in the range of 0.5 to 4.1 for coarse grains, 0.4 to 3.4 for sugar and 1.2 to 3.5 for oil seeds⁹.

Further we looked at the case where the waiver was only given in the EU and was not a global waiver. The effect of operating the waiver only in the EU is to make the fall in price slightly smaller at the upper end of the range. Working with the same concept of the elasticity of the price of the feedstocks with respect to the fall in the yield for coarse grains are in the range of 0.5 to 3.8. In the case of sugar crops, the range declines to 0.4 to 2.8 and in the case of oilseeds it declines to 1.0 to 2.8.

5.4. Change in waiver to year $T + 1$

We examine the timing of waiver, what happens when the waiver is imposed in year $T + 1$ when the fall in yields was in year T . In other words, this is to see what happens if there is a delay on the part of the policy makers to react to an increase in the prices of feedstocks. The motivation is that it may be too late for the waiver to be introduced in the year of the shock, so by the time it can be made effective we are in year $T + 1$. Table 8 provides the effect of the delay in the waiver for all four variants.

The effect of the delay depends very much on the conditions that prevail in the year when the waiver is imposed. In Variant I, the waivers are given in years 2015 and 2016 instead of 2014 and 2015. The waiver effect reduce prices significantly in 2016 but fails to make any impact on the large price increases in 2014. The results for 2015 are similar in both cases. With Variant II, the waivers are moved to 2019 and 2020 instead of 2018 and 2019. Now the 2019 results are similar but the large increases in prices in 2018 are not reduced while the modest falls in 2020 are made much greater.

In Variant III, the waivers are imposed in 2017 and 2019 instead of 2016 and 2018. In 2017 prices are reduced a lot for oilseeds and sugar crops when they were going to go up a moderately. In 2016 and 2018 the system fails to moderate the large increases and finally in 2019 it reduces the increases, some of which were in fact quite large. Finally, for Variant IV, the waivers are moved to

⁸ One may question whether the authorities know of the fall in yields early enough in the year in which they occur to introduce a 90% waiver. This may be a problem, although information from early warning systems can provide advance notice to permit such a policy. In the case where it cannot we also consider the case where the waiver is implemented in the following year.

⁹ The counterfactual for the comparison is the price that would have prevailed with no waiver.

2018 and 2019 from 2017 and 2018. In this case 2018 is a common year with the same results but the 2017 increases are not reduced and in 2019 there is a big decrease in prices.

Table 8. Change in prices of feedstocks when waiver is in year T+1.

| | With waivers in years T+1 | | | With waivers in years T | | | | |
|---------------|---------------------------|-------|-------|-------------------------|-------|------|------|------|
| | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 | | |
| Variant I | 2014 | 2015 | 2016 | 2014 | 2015 | 2016 | | |
| Coarse Grains | 40.9 | -7.4 | -29.8 | 30.3 | -7.4 | -4.0 | | |
| Oil Seeds | 63.0 | -16.3 | -28.8 | 15.8 | -16.3 | -3.5 | | |
| Sugar Crops | 38.6 | -7.3 | -28.1 | 46.4 | 7.3 | -5.3 | | |
| Variant II | 2018 | 2019 | 2020 | 2018 | 2019 | 2020 | | |
| Coarse Grains | 44.1 | 1.5 | -15.9 | 20.0 | 1.6 | -2.0 | | |
| Oil Seeds | 44.7 | -13.4 | -69.9 | 17.9 | -13.4 | -2.8 | | |
| Sugar Crops | 25.4 | 9.7 | -17.0 | -1.5 | 9.7 | -2.5 | | |
| Variant III | 2016 | 2017 | 2018 | 2019 | 2016 | 2017 | 2018 | 2019 |
| Coarse Grains | 46.1 | 5.7 | 44.1 | 40.6 | 17.7 | 4.4 | 8.0 | 41.4 |
| Oil Seeds | 30.7 | -25.2 | 25.1 | -9.6 | 3.5 | 14.5 | 11.9 | 9.0 |
| Sugar Crops | 47.0 | -20.5 | 44.7 | 12.4 | 22.5 | 15.6 | -0.2 | 16.2 |
| Variant IV | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 | | |
| Coarse Grains | 12.8 | 8.4 | -1.5 | -1.4 | 8.3 | 32.8 | | |
| Oil Seeds | 8.6 | -2.4 | -10.6 | -2.2 | -2.4 | 5.1 | | |
| Sugar Crops | 14.2 | 16.3 | 9.4 | 8.8 | 16.3 | 12.3 | | |

6. Conclusions

The study focused on the recent trends and mandates of the biofuels of the three important markets: Brazil, the EU and USA and analyzed the prices of biofuel crops. In order to capture the economy-wide effects, the analysis was carried out by using the computable general equilibrium model. The results of the calibrated model reveal that the returns to biofuel producers are expected to increase significantly over the period of 2012–2020. During this period, due to the changes in the prices of the feedstocks and biofuel crops, the biofuel market is expected to grow from 78 billion to 145 billion liters in all three regions. In EU region alone, ethanol from grains is expected to increase by 290% by year 2020. On the other hand, biodiesel production is expected to for 7.5 billion to 11.9 billion liters in 2020 (an increase of 60%). For higher returns, the producers are expected to fix the supply side of the market, they determine the output to maximize profits as function of input and output prices. On the other hand, demand side is expected to determine by the prices and government regulations on the fuel mix for transportation. The study assume that the current regulations continue, and to meet the mandate requirement, countries import the biofuels whenever the prices of feedstocks are in domestic market.

The sensitivity analysis of the key parameters indicates that a higher elasticity of substitution between fossil fuel and biofuels results in a greater demand for biofuels when yields of feedstocks rise and prices of feedstocks fall. This effect is present even with variations in yields of the kind observed in the past 20 years. The sensitivity test to the price of crude oil reveals that, whenever crude oil prices are lower than in the baseline, the demand for fossils increases and lower that for biofuels when the two are substitutes. However, part of the demand for biofuels is complementary to that for fossil fuels (in transport) and there are also general equilibrium effects. Consequently the

overall change in demands and prices for biofuels are unclear. The simulations show that when crude oil prices rise biofuel prices and prices of feedstocks rise as well but when crude oil prices fall the effects are more mixed.

The study observes that declines in yields feed through significantly to increases in the prices of coarse grains, oilseeds and sugar crops and vice-versa. And also observes that the impact of the changes in yields on the prices of biofuels is very small. This may be due to the fact that biofuel output process is linked to the price of petroleum products and cannot respond to the increase in the price of feedstocks. The consequence of these two phenomena is that when yields decline and prices of feedstocks rise the returns to biofuels decline very sharply and conversely when the price of feedstocks fall, the returns to biofuels increase sharply.

Later the study investigated the changes in mandates for biofuels in all the three regions. In order to estimate the impacts of changes in formal and informal regulations, we consider various hypothetical fluctuations in the yields and assumed 35% lower production of biofuels in different years. We observe that in each variant, when prices fall as a result of higher yields, the observed fall is greater when demand for biofuels is reduced by 35%. And, when prices rise as a result of lower yields, the observed rise less when biofuel demand is reduced by 35%.

We observe much smaller impacts of mandates in the EU27 region compared to results when all three regions impose a mandate change. For coarse grain, a one percent increase in price would reduce by only one percent, whereas this impact was much larger in the case of all three region model (5 to 14%). For sugar crops, a one percent increase in prices would now reduce by 7–11%. This reduction was 11–13% in case the three region model. For biofuel crops a one percent increase in price would reduce by 17 to 52% in the EU27 region model, whereas this impact was much bigger in the case of three region model (17–82%). The modelling of increases in mandates confirms the above results. An increase in production of 35% in the target for Brazil, the EU and USA would raise prices, depending on what conditions prevail in the feedstock market.

When yields for feedstocks are particularly low it is possible to consider a waiver in production for biofuel. This was modelled by looking at a 90% reduction in biofuel production in the selected countries in years when yields are simulated to be exceptionally low. The model indicates that if a global waiver of 90% is made in the selected years then price rises can be reduced very significantly for oilseeds but less so for sugar crops and coarse grains.

Acknowledgments

The authors would like to acknowledge Sustainability Services Deloitte Conseil, France for supporting this research. We thank Mr. Sébastien Soleille and three anonymous reviewers for their valuable comments and suggestions in shaping up this paper.

Conflict of interest

All authors declare no conflicts of interest in this paper.

References

1. EIA (2015) Biofuels Production and Consumption, IEA-US Energy Information Administration database. Available from: https://www.eia.gov/beta/international/data/browser/#/?pa=000002&c=rurvfvvtvnnvvlurvfvfvvvvvfvvvvou20evvvvvvvvvvnnvvuvo&ct=0&tl_id=79-A&vs=INTL.79-1-AFG-TBPD.A&vo=0&v=H&start=2000&end=2016.
2. von Lampe M (2008) Biofuel support policies: an economic assessment. Paris: OECD. Available from: http://www.oecd-ilibrary.org/energy/biofuel-support-policies-an-economic-assessment_9789264050112-en.
3. European Commission (2003) Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. Off. J. L 123. Available from: <https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32003L0030>.
4. European Commission (2009) Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. J Eur Union L 140, 47. Available from: <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0028>.
5. European Biodiesel Board (2015) EU Biodiesel Industry: Production by Country. Available from: <http://www.ebb-eu.org/stats.php#>.
6. USDA ERS-U.S. Bioenergy Statistics. Available from: <https://www.ers.usda.gov/data-products/us-bioenergy-statistics/>.
7. Mitchell D (2008) A note on rising food prices. World Bank Washington, DC.
8. Zhang W, Elaine AY, Rozelle S, et al. (2013) The impact of biofuel growth on agriculture: Why is the range of estimates so wide? *Food Policy* 38: 227–239.
9. Hertel TW, Tyner WE, Birur DK (2010) The global impacts of biofuel mandates. *Energ J* 31: 75–100.
10. Taheripour F, Hertel TW, Tyner WE (2011) Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis. *Agr Econ* 42: 325–342.
11. Beckman J, Jones CA, Sands R (2011) A global general equilibrium analysis of biofuel mandates and greenhouse gas emissions. *Am J Agr Econ* 93: 334–341.
12. Britz W, Hertel TW (2011) Impacts of EU biofuels directives on global markets and EU environmental quality: An integrated PE, global CGE analysis. *Agr Ecosyst Environ* 142: 102–109.
13. Diffenbaugh NS, Hertel TW, Scherer M, et al. (2012) Response of corn markets to climate volatility under alternative energy futures. *Nat Clim Change* 2: 514.
14. Hausman C, Auffhammer M, Berck P (2012) Farm Acreage shocks and crop prices: An SVAR approach to understanding the impacts of biofuels. *Environ Resour Econ* 53: 117–136.
15. Roberts MJ, Schlenker W (2010) The US biofuel mandate and world food prices: an econometric analysis of the demand and supply of calories. NBER Working Paper 15921.
16. Chakravorty U, Hubert M-H, Moreaux M, et al. (2012) Do biofuel mandates raise food prices. AERE Annual Meeting, Ashville, NC, USA. Available from: https://www.researchgate.net/profile/David_Zilberman/publication/265144230_Do_Biofuel_Mandates_Raise_Food_Prices/links/5457b5db0cf26d5090ab4fa7.pdf.

17. Lipsky J (2008) Commodity prices and global inflation. Remarks at the Council of Foreign Relations, New York.
18. Algieri B (2014) The influence of biofuels, economic and financial factors on daily returns of commodity futures prices. *Energ Policy* 69: 227–247.
19. Linares P, Pérez-Arriaga IJ (2013) A sustainable framework for biofuels in Europe. *Energ Policy* 52: 166–169.
20. Zilberman D, Hochman G, Rajagopal D, et al. (2012) The impact of biofuels on commodity food prices: Assessment of findings. *Am J Agr Econ* 95: 275–281.
21. Condon N, Klemick H, Wolverson A (2015) Impacts of ethanol policy on corn prices: A review and meta-analysis of recent evidence. *Food Policy* 51: 63–73.
22. Al-Riffai P, Dimaranan B, Laborde D (2010) Global trade and environmental impact study of the EU biofuels mandate. International Food Policy Research Institute. Washington DC. Available from: <http://www.ifpri.org/publication/global-trade-and-environmental-impact-study-eu-biofuels-mandate>.
23. Hertel TW, Beckman J (2011) Commodity price volatility in the biofuel era: An examination of the linkage between energy and agricultural markets. In: *The Intended and Unintended Effects of US Agricultural and Biotechnology Policies*. University of Chicago Press, 189–221.
24. Adusumilli N, Leidner A (2014) The US biofuel policy: review of economic and environmental implications. *Ind Eng Chem Res* 2: 64–70.
25. Jaiswal D, De Souza AP, Larsen S, et al (2017) Brazilian sugarcane ethanol as an expandable green alternative to crude oil use. *Nat Clim Change* 7: nclimate3410.
26. Falcone PM, Lopolito A, Sica E (2018) The networking dynamics of the Italian biofuel industry in time of crisis: Finding an effective instrument mix for fostering a sustainable energy transition. *Energ Policy* 112: 334–348.
27. De Gorter H, Just DR (2009) The economics of a blend mandate for biofuels. *Am J Agr Econ* 91: 738–750.
28. Hunsberger C, Bolwig S, Corbera E, et al. (2014) Livelihood impacts of biofuel crop production: Implications for governance. *Geoforum* 54: 248–260.
29. Taheripour F, Hertel TW, Tyner WE, et al. (2010) Biofuels and their by-products: Global economic and environmental implications. *Biomass Bioenerg* 34: 278–289.
30. Taheripour F, Tyner WE (2014) Welfare assessment of the renewable fuel standard: economic efficiency, rebound effect, and policy interactions in a general equilibrium framework. In: *Modeling, Dynamics, Optimization and Bioeconomics I*. Springer, 613–632.
31. Birur D, Hertel T, Tyner W (2008) Impact of biofuel production on world agricultural markets: a computable general equilibrium analysis. GTAP working paper. Available from: <https://www.gtap.agecon.purdue.edu/resources/download/4034.pdf>.
32. Chappuis T, Walmsley T (2011) Projections for World CGE Model Baselines. Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University. Available from: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.386.8726&rep=rep1&type=pdf>.
33. OECD-FAO (2012) OECD-FAO Agricultural Outlook 2012–2021. Available from: https://stats.oecd.org/Index.aspx?DataSetCode=HIGH_AGLINK_2012.
34. Golub A, Hertel T, Rose S, others (2014) Global land use impacts of US ethanol: static vs. dynamic economic modeling. In: 2014 Annual Meeting, July 27–29, 2014, Minneapolis, Minnesota.

-
35. McDaniel CA, Balistreri EJ (2003) A review of armington trade substitution elasticities. *Econ Int* 2: 301–313.
 36. Welsch H (2008) Armington elasticities for energy policy modeling: Evidence from four European countries. *Energ Econ* 30: 2252–2264.



AIMS Press

© 2018 the Author(s), licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>)