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The role of flexible biofuel policies in meeting biofuel mandates

Anil Markandya[a], Kishore Dhavala[b] and Alessandro Palma[c]

This study analyzes the role of biofuels in different markets. It focuses on the link between volatility in the yields of feedstocks and how these feed through to changes in the prices of biofuel crops under different rules for managing biofuel mandates. Under current mandates the impact seems to be significant, with the greatest being on price of sugar crops, followed by grains and oilseeds. Changes in mandates have different results in the EU, depending on crops and change in yields examined. The paper also looks at the implications of waivers in 'bad' years.

Keywords: biofuel mandates, elasticity of substitution, volatility of prices, waivers.

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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 countries 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 countries, for the period 2000–2012, global biofuel production has increased from 18 billion litres to 83 billion litres (OECD, 2008; EIA, 2015).

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 5 years (2007–2012) US ethanol production has doubled from 18.5 billion litres to 38 billion litres (EIA, 2015). During the same time, European countries have designed several policies 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 (European Commission, 2003) and the Renewable Energy Directives, which imposed a target of 10% renewable energy in road transport fuels by 2020 (European Commission, 2009). These polices have influenced biodiesel growth in EU; for the period 2007–2013, the biodiesel production has increased from 6 billion litres to 12 billion litres (OECD, 2008; EBB, 2015).

For ethanol production the US has been largely depending on maize production. Around one fourth of the ethanol comes from maize, around 50% of Brazil´s ethanol comes from sugar cane, whereas in EU approximately 68% of the biodiesel comes from vegetable oil production, primarily rapeseeds (Mitchell, 2008; Zhang et al., 2013). 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. Studies (Hertel et al., 2010; Taheripour et al., 2011; Beckman et al., 2011; Britz and Hertel, 2011) have argued that the share of biofuel crops and feedstock production will grow significantly with the existing mandates.

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. (2012) suggest that with the current climate conditions, energy policies and energy market integration, there would be a sharp increase in the USA corn price. Hausman et al. (2012) predict that the corn price would increase by 33%, Roberts and Schlenker (2010) and Chakravorty et al. (2012) suggest that the food prices would increase by 20–32% by year 2020. Mitchell's (2008) study projects a 70% increase in food prices, Lipsky (2008) predicts a 70% increase in maize and 40% increase in soybean prices. Using time series analysis, Algieri (2014) finds that oil and ethanol returns have a significant influence on corn, wheat, sugar and soybeans. 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 and Pérez-Arriaga (2013).

The estimates of these studies differ widely due to the data sets, time periods, types of products and the methodology they have used. For instance, Condon et al. (2015) review studies published between 2007 and 2014 whose estimations of U.S. corn ethanol policy on corn prices range from nil to over 80 percent. 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 3–4 percent 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 (GTAP), 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 in 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. The model

For the analysis, we used GTAP-BIO database in which Taheripour et al. (2010) 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. 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. (2010) 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.

$$\sigma = (qe - q)/(p - pe) \qquad (1)$$

Equation (1) has taken from Hertel et al. (2010), where represents σ the elasticity of substitution, qe is the percentage change demand for ethanol/biodiesel, , q, the aggregated demand for liquid fuels and $(p - pe)$ is the composite price of liquid fuels.

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 petroleum. 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 Equation (1)

$$D_e = q - \sigma_{ELIHBIOOIL} * (p_e - p) \quad (2)$$

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

$$D_{bd} = q - \sigma_{ELIBIOD} * (p_{bd} - p) \quad (3)$$

where q is the aggregate household demand for liquid fuels, $p_e - p$ and $p_{bd} - p$ represents the price share of ethanol and biodiesel relative to a composite energy price index for commodities consumed by households. $\sigma_{ELIHBIOOIL}$ and σ_{ELBIOD} are the elasticities of substitution between liquid fuels. The share of ethanol/gasoline (blend) and biodiesel have been assumed as constant and, do not depend on the oil price. Thus the percentage 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.

2.1 Biofuel and biodiesel production

On the supply side, biofuels are a complement to petroleum products in the production process. Constant returns to scale in ethanol/biodiesel production are assumed, giving zero profits in the medium run. Percentage price changes for ethanol producers depend on the input price changes and on the cost share of the input.

In the GTAP-BIO economy, ethanol output is determined by: 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 subsides 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 for each sector based on these conditions. The zero profit condition provides the following relationship (the equations are obtained from Taheripour et al., 2010).

$$ps_j = \sum_i \theta_i pf_{ij} \quad \text{for } j = \text{Ethanol, Biodiesel} \quad (4)$$

Here $ps_j, \theta_i,$ and pf_{ij} represent the percentage change in price of output in the sector $j =$ Ethanol and Biodiesel, the share of input i in total costs of producing commodity j, and the percentage 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 (Hertel and Beckman, 2011), 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 equation (4) the subsidy would modify the equation to:

$$ps_j(1 + \varphi_j) = \sum_i \theta_i pf_{ij} \quad \text{for } j = \text{Ethanol, Biodiesel} \quad (5)$$

where φ is the subsidy given as a percentage 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. Taheripour et al., 2010; 2011 and Taheripour and Tyner, 2014). 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. Golub et al., 2014) 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:

Swap *qo*("Ethanol","EU") = *tpd*("Ethanol","EU") ; Shock *qo*("Ethanol","EU") = X

where X indicates the level of shock (in percentage), *qo* is the biofuel output, *tms* (or *tpd*) is the values of bilateral import taxes. We also imposed a revenue-neutral subsidy with the following shock:

Swap del_*taxrpcbio*("EU") = *tpbio*("EU");

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 ($\sigma_{ELIHBIOOIL}$), which we observed from the empirical estimation by Birur et al. (2008). 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 low elasticity for Brazil takes into account the fact that ethanol plays the lion's share in the biofuel market and large percentage changes become more difficult as ethanol grows. The higher US elasticity compared to the EU elasticity reflects the higher growth of EU renewable fuels during the estimation period (2001–2006).

3. Model simulation

3.1 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 into 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., (2011). 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 descried in Section 2.1. The historical matching of the biofuel sector reproduced by the model is validated by using the OECD-FAO (2012) projections for agricultural yields over the period 2004–2012.

3.2 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 Golub et al., 2014). As stressed in Hertel et al. (2010), 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). We have 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)[1].

Predictions 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 the EU and Brazil. As expected these declines feed through to lower prices for biofuels as well and we 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.

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. Sec	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_Oil1	-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 CO_2 Emissions, En._Int._Ind.: Energy intensive industries, Oth._Ind._Se.: Other industries and services, Oth. Prim. Sect: Other primary products, Ethanol1: Ethanol produced from grains, Ethanol2: Ethanol produced from sugarcane, DDGS: Dried distillers grains with solubles, Cveg_Oil1: crude Vegetable oils and fats, VOBP: Soybean meals, CGDS: Agg. capital goods.

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%)[2]. In the EU ethanol

1: 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.

from grains is expected to grow from 2.8 billion liters to 10.9 billion liters, an increase of 290%. Biodiesel in the EU on the other hand grows more slowly – from 7.5 billion liters to 11.9 billion liters, an increase of 60%. There is also a significant increase in ethanol from sugarcane in Brazil: from 15.3 billion liters to 43.7 billion liters, an increase of 186%.[3]

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.

3.3 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 on-coal energy; d) variations in the Armington[4] elasticity between imported and domestic versions of a given commodity. In the case of assumptions (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 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). The effects for rises and falls in the elasticity of substitution appear to be quite symmetric.

2: http://stats.oecd.org/index.aspx?queryid=36348#

3: 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). The latter provides figures only for the EU and the absolute values are different from the FAO/OECD study but both of them have very similar growth rates. From 2012 to 2020 the FAO/OECD study projects growth rates for ethanol and biodiesel of 8.0% and 5.2% respectively. The EU study has growth rates of 8.1% and 5.4%. Since absolute values are not critical to our flexibility study we can work with the FAO/OECD data.

4: 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 McDaniel and Balistreri, (2002) and Welsch (2008) for further details.

Table 2: Sensitivity analysis for elasticities

% Change in Prices Relative to Base Case			
	USA	EU	Brazil
If Elasticity of Substitution Between Fossil Fuels and Biofuels is 30% Higher:			
Cr. Grains	8.00%	2.20%	2.70%
Oil Seeds	4.70%	5.70%	4.00%
Sugar Crop	5.10%	1.80%	10.20%
Ethanol 2	0.10%	0.20%	4.10%
Ethanol 1	4.30%	0.50%	0.90%
Biodiesel	13.10%	9.30%	2.90%
DDGS	2.60%	2.50%	3.20%
If Elasticity of Substitution Between Fossil Fuels and Biofuels is 30% Lower:			
Cr. Grains	-8.00%	-2.20%	-2.70%
Oil Seeds	-4.70%	-5.70%	-4.00%
Sugar Crop	-5.10%	-1.80%	-10.20%
Ethanol 2	-0.10%	-0.20%	-4.10%
Ethanol 1	-4.30%	-0.50%	-0.90%
Biodiesel	-13.10%	-9.30%	-2.90%
DDGS	-2.60%	-2.50%	-3.20%
If Elasticity of Substitution Between Capital and Energy is 30% Higher			
Cr. Grains	0.00%	0.00%	0.00%
Oil Seeds	0.00%	0.00%	0.00%
Sugar Crop	0.00%	0.00%	0.00%
Ethanol 2	0.00%	0.00%	0.00%
Ethanol 1	0.00%	0.00%	0.00%
Biodiesel	0.00%	0.00%	0.00%
DDGS	0.00%	0.00%	0.00%
If Elasticity of Substitution Between Capital and Energy is 30% Lower			
Cr. Grains	0.00%	0.00%	0.00%
Oil Seeds	0.00%	0.00%	0.00%
Sugar Crop	0.00%	0.00%	0.00%
Ethanol 2	0.00%	0.00%	0.00%
Ethanol 1	0.00%	0.00%	0.00%
Biodiesel	0.00%	0.00%	0.00%
DDGS	0.00%	0.00%	0.00%

% Change in Prices Relative to Base Case			
	USA	EU	Brazil
If Elasticity of Substitution Between Coal and Non-Coal Energy is 30% Higher			
Cr. Grains	0.60%	0.00%	0.10%
Oil Seeds	0.10%	0.00%	0.10%
Sugar Crop	0.30%	0.00%	0.10%
Ethanol 2	0.00%	0.00%	0.00%
Ethanol 1	0.50%	0.00%	0.00%
Biodiesel	0.10%	0.00%	0.00%
DDGS	0.50%	0.20%	0.20%
If Elasticity of Substitution Between Coal and Non-Coal Energy is 30% Lower			
Cr. Grains	-0.60%	0.00%	-0.10%
Oil Seeds	-0.10%	0.00%	-0.10%
Sugar Crop	-0.30%	0.00%	-0.10%
Ethanol 2	0.00%	0.00%	0.00%
Ethanol 1	-0.50%	0.00%	0.00%
Biodiesel	-0.10%	0.00%	0.00%
DDGS	-0.50%	-0.20%	-0.20%
If Armington Elasticity Between Domestic & Imported allocation is 30% Higher			
Cr. Grains	8.30%	4.50%	5.70%
Oil Seeds	23.40%	3.20%	18.50%
Sugar Crop	9.00%	3.00%	9.40%
Ethanol 2	0.20%	0.20%	3.70%
Ethanol 1	1.60%	3.60%	3.10%
Biodiesel	4.20%	1.20%	13.50%
DDGS	6.80%	5.90%	4.90%
If Armington Elasticity Between Domestic & Imported allocation is 30% Lower			
Cr. Grains	8.30%	4.50%	5.70%
Oil Seeds	23.40%	3.20%	18.50%
Sugar Crop	9.00%	3.00%	9.40%
Ethanol 2	0.20%	0.20%	3.70%
Ethanol 1	1.60%	3.60%	3.10%
Biodiesel	4.20%	1.20%	13.50%
DDGS	6.80%	5.90%	4.90%

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. 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.

For the price of crude oil that is different from the baseline we took projections as given by the US Energy Information Administration (EIA) for the period 2014–2020. To test the impacts simulations were carried out for two years: 2014, 2020. 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.

4. Impacts of volatility in the supply of biofuels

4.1 Impacts of changes in yields

The estimated changes in yields between 2012 and 2020 as given in the FAO report 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 Brazil[5]. 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. The variations are given in the following table:

Table 3: Future fluctuations in terms of possible variants

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

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[6]. 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 4). The impact of changes in yields is greater on price in the case of sugar crops, followed by grains and oilseeds. The results tells us that for coarse grains a one percent increase in yield results in a fall in the price of between 1.1 to 2.4 percent, in case of oil seeds the fall will be between 1.2 and 1.8 percent and for sugar crops, it will be in between 1.3 and 2.9 percent.

5: Based on data from 1995 to 2012, taken from FAO.
6: Similar results for the other variants are available on request.

Table 4: 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

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 are 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 percentage 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).

4.2 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 demand that a given percentage 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 system.[7] A change in the mandate is a change in the demand side of the market for biofuels. When there is a reduction of, e.g 35% then demand is lowered by this amount and prices of feedstocks fall. Table 5 provides the feedstock prices with and without a 35% reduction biofuel production.

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 5: 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
Coarse Grains					***Coarse Grains***				
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
Percentage Impact of 35% Mandate	**0.40**	**-0.01**	**-0.05**	**0.26**	**Percentage Impact of 35% Mandate**	**0.44**	**0.07**	**0.26**	**-0.07**
Sugar Crops					***Sugar Crops***				
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
Percentage Impact of 35% Mandate	**0.65**	**-0.02**	**-0.05**	**0.30**	**Percentage Impact of 35% Mandate**	**0.71**	**0.06**	**0.13**	**-0.11**
Oil Seeds					***Oil Seeds***				
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
Percentage Impact of 35% Mandate	**0.34**	**-0.11**	**-0.22**	**0.34**	**Percentage Impact of 35% Mandate**	0.45	0.30	0.30	-0.17
Variant III	2013	2014	2015	2016	**Variant IV**	2013	2014	2015	2016
Coarse Grains					***Coarse Grains***				
Change in Yield (%)	1.41	-3.66	5.00	-18.00	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	-28.11
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	-28.76
Percentage Impact of 35% Mandate	0.34	-0.14	0.10	-0.05	**Percentage Impact of 35% Mandate**	0.34	0.05	0.04	0.02
Sugar Crops					*Sugar Crops*				
Change in Yield (%)	0.46	-4.56	6.53	-16.81	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	-30.90
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	-27.50
Percentage Impact of 35% Mandate	0.56	-0.13	0.09	-0.11	**Percentage Impact of 35% Mandate**	0.56	0.05	0.04	-0.11
Oil Seeds					*Oil Seeds*				
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	-20.27
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	-16.83
Percentage Impact of 35% Mandate	0.16	-0.82	-0.82	-0.17	**Percentage Impact of 35% Mandate**	-0.21	0.14	0.14	-0.17

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 percentage change.

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 show 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%.

More clearly, in the case of Variant I, for coarse grains a one percent rise in prices is reduced by about 1 to 5 percent and by 5 to 14 percent in the case of Variant III. On the other hand a one percent fall in prices is made bigger by 26 to 40 percent[8] in case of Variant I and 5 to 35 percent in case of Variant IV. For sugar crops a one percent rise in prices is reduced by 2 to 5 percent in the case of Variant I and by 11 to 13 percent in the case of Variant III, while a one percent fall in prices is made bigger impact by 30 to 65 percent in the case of Variant I and by 4 to 56 percent in the case of Variant IV. For biodiesel crops the results show that a one percent rise in price is reduced by 11 to 22 percent in case of Variant I and the impact is much bigger in case of Variant III (17 to 82 percent) while a one percent fall in prices increase by 34 percent in the case of Variant I and 16 to 22 percent in the case of Variant IV.

Our results thus show a clear asymmetry in 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 percent in the target for Brazil, the 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 last 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 last for coarse grains.

Further the analysis was done to compare the price change of EU27 within all three regions against the EU alone. The mandate impacts are much smaller in the EU27 region compared to all the three regions. In case of EU 27 alone, for coarse grain, a one percent increase in price would reduce 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 percent, and for sugar crops, that would now reduce by 7 to 11 percent. Biofuel crops are price sensitive, a one percent increase in price would reduce by 17 to 52 percent in the EU27 region model, whereas this impact was much bigger in the case of three region model (17–82 percent).

4.3 Measures to reduce the impact of volatility in yields: waivers

Another policy that could be used to address years with low yields is one of 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 compared to the baseline: Variant I: 2014 and 2015, when yields for the three feedstocks are made to fall by around 19–20 and 13–14 percent respectively; Variant II: 2018 and 2019, when yields for the three feedstocks are made to fall by around 13–15 and 13–14 percent respectively; Variant III: 2016 and 2018, when yields for the three feedstocks fell by 16–18 and 7–10 percent respectively; Variant IV:

7: Note that here we are referring to a percent change on a percent, so if a fall in prices is reduced from 21.8% to 20.7%, the fall of 0.9% is a decline of 4%. Similarly is the fall in price is raised from 4% to 5% the fall is said to be 25% higher.

2017 and 2018 when yields for the three feedstocks fell by 9–10 and 12–13 percent respectively. Table 6 provides the change in the prices of feedstocks with 90% waiver.

Table 6: Impacts of a 90% waiver for biofuel production in EU27

Variant I	**2014**	**2015**	**Variant II**	**2018**	**2019**
Coarse Grains			***Coarse Grains***		
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
Sugar Crops			***Sugar Crops***		
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
Oil Seeds			***Oil Seeds***		
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**
Coarse Grains			***Coarse Grains***		
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
Sugar Crops			***Sugar Crops***		
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
Oil Seeds			***Oil Seeds***		
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 percentage change.

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 yields[9]. 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 seeds[10].

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 smaller. Working with the same concept of the elasticity of the price of the feedstocks with respect to the fall in the yield the figures for coarse grains are in the range of 0.5 to 3.8. In the case of sugars the range declines to 0.4 to 2.8 and in the case of oilseeds it declines to 1.0 to 2.8.

9: 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.

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

4.4 Change in waiver to year $T + 1$

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 7 provides the effect of the delay in the waiver for all four variants.

Table 7: Change in prices of feedstocks when waiver is in year T+1

	With waivers in years T+1				With waivers in years T			
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	
	With waivers in years T+1				With waivers in years T			
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	
	With waivers in years T+1				With waivers in years T			
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
	With waivers in years T+1				With waivers in years T			
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	

Note: See the Table 2 for description of the Variants. Gray shade represents the year when the waiver was introduced.

The effect of the delay depends very much on the conditions that prevail in the year when the waiver is now imposed. With Variant I the waivers are given in years 2015 and 2016 instead of 2014 and 2015 and the effect is to 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 now 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 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.

5. Conclusions

In this study we focused on the recent trends and mandates of the biofuels in 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 calibrated model estimates that output of biofuels would grow globally, and in the three selected regions it is expected to grow by 54 percent. In the EU ethanol from grains is expected to grow by 85 percent and biodiesel is expected to grow by 49 percent. The base case outlook is for falls in prices of the feedstocks for biofuels of 10 to 20 percent, which in turn result in lower prices for the biofuels themselves. From the producers' perspective, these changes should result in higher profits.

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. Later, the model was tested for sensitivity to the price of crude oil. If crude oil prices are lower than in the Base Case the direct effect is to increase the demand for fossil fuels 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 tests of volatility of prices as a result of changes in yields for feedstocks reveal that such changes feed through to increase the prices of coarse grains, oilseeds and sugar crops significantly. The impact seems to be greatest on price in the case of sugar crops, followed by grains and oilseeds. On the other hand the effect of the changes in yields on prices of biofuels is small.

Changes in mandates for biofuels were examined by looking at a 35% decrease in the required amount in Brazil, the EU and USA, as well as a 35% increase. For coarse grains a one percent rise in prices is reduced by about 1–14 percent while a one percent fall in prices is made bigger by 5–35 percent. For sugar crops each one percent rise in prices is reduced by 2–13 percent while a one percent fall in prices is made bigger by 4–71 percent. For biodiesel crops the results show that each one percent rise in price is reduced by 11–22 percent while a one percent fall in prices is made bigger by 16–22 percent. There is thus an asymmetry between the effect of the mandate change in the case of an increase in yields and decrease in yields.

The mandate impacts are much smaller 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 percent). For sugar crops, a one percent increase in prices would now reduce by 7–11 percent. This reduction was 11–13 percent in case the three region model. For biofuel crops a one percent increase in price would reduce by 17 to 52 percent in the EU27 region model, whereas this impact was much bigger in the case of three region model (17–82 percent).

The modelling of increases in mandates confirms the above results. An increase in production of 35 percent 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.

The paper also considered the case where the waiver is given one year later than the year in which the yields fell and prices rose. The consequences of this are obvious in most respects: price falls do not take place in the year in which they went up sharply but they fall slightly in the subsequent year. If that is also a year when a waiver is appropriate the same effect is observed as with a no delay policy.

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