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# GLOBAL IMPACTS OF THE BIOFUEL MANDATE UNDER A CARBON TAX

UJJAYANT CHAKRAVORTY AND MARIE-HÉLÈNE HUBERT

Many countries are actively promoting biofuel mandates as a means of reducing carbon emissions and dependence on imported oil. In the United States, the Federal Renewable Fuel Standard (RFS) calls for the minimum use of 15 billion gallons per year of corn ethanol by 2015. Beyond 2015, the mandate calls for a steady increase in the use of second generation biofuels to a level of 21 billion gallons in 2022. The EU biofuels mandate requires the share of biofuels to rise from the current share of 4% to 10% in 2020.

An important goal of these energy mandates is to reduce GHG emissions. However, many studies suggest that biofuel policies do not induce significant reductions in emissions. [Chen, Huang and Khanna \(2012\)](#) develop a model of the US food and fuel sectors and conclude that the impact of the mandate alone in reducing GHG emissions is small, but increases when the mandate is accompanied by a subsidy for second generation biofuels or a carbon tax. Other studies find that the biofuel mandate can cause an *increase* in direct GHG emissions ([de Gorter and Just 2009](#)). By lowering the price of the blending fuel, the mandate when combined with a tax credit results in an increase in fuel consumption, which can raise GHG emissions. [Lasco and Khanna \(2010\)](#) develop a partial equilibrium model of the US fuel sector and show that a combined subsidy and tariff increases ethanol demand and domestic production in the US. GHG emissions increase compared to the no-intervention case. However, all studies agree on one point: biofuel

mandates lead to an increase in indirect carbon emissions ([Searchinger \*et al.\* 2008](#); [Chen, Huang and Khanna 2012](#)).

None of these papers examine the joint effects of the US and EU mandates and a carbon tax on a global model. We focus on this issue using a partial equilibrium model of the world food and fuel markets developed by [Chakravorty \*et al.\* \(2012\)](#). This model is unique because it traces the effects of biofuel policies by allowing for the endogenous conversion of marginal lands to farming in order to produce food and fuel. It determines where the biofuels and food should be produced and on what quality of land (low, medium or high). Two biofuel policies are considered. First, we focus on the US and EU mandates without any carbon tax. In the second scenario, the two mandates are accompanied by a carbon tax. In the regulated countries, the mandates reduce gasoline consumption and GHG emissions by triggering a switch towards biofuels. But it differs from a carbon price instrument in that it lowers the price of vehicle miles traveled (VMT) and leads to a rise in the consumption of blended fuels. When the mandates are imposed together with a carbon tax, direct emissions are lower in the regulated countries.

Biofuel use in the US does not change significantly with a carbon tax, when the mandate is in place. Hence indirect emissions do not change appreciably in other countries that produce and export biofuels to the US. Under both policies, there is a leakage effect on the rest of the world. However, what changes is gasoline consumption. When the mandate is combined with the tax instrument, gasoline use is lower in the US, hence leakage is higher in the rest of the world. Direct carbon emissions in the aggregate, go up. Indirect carbon emissions also increase some when the mandate is combined with the tax. Since carbon emissions from biofuels are released during their production, a carbon tax in the

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regulated countries improves the competitiveness of imported biofuels. Acreage brought into cultivation increases causing a rise in indirect carbon emissions.

We next describe the model used. Impacts of biofuel policies on food and fuel markets and on GHG emissions are described in section 3. Finally, section 4 concludes.

## The model

The world economy is composed of five regions, described below. Each region supplies and consumes two food commodities (cereals; and meat/dairy) and fuel for transportation. Transport fuel is domestically produced from a blend of gasoline and biofuels. Biofuels may be first or second generation biofuels. Gasoline is produced from crude oil and its price depends on the world oil market. Biofuels and food commodities are traded between regions. In each region, available land may be allocated to food or energy.

The regions we consider are: High Income Countries (HICs), Medium (MICs) and Low Income Countries (LICs), classified by gross national product per capita. The HICs are then divided into three groups: US, EU and other HICs since our study focuses on US and EU mandatory blending policies. Fast-growing countries like China, India and Brazil are included in the MICs whose average gross national product per capita was about US\$5,700 in 2007, the benchmark year for the model. Finally, the LICs are mainly nations from Africa with average gross national product per capita of about \$1,060 in 2007.

Demands for the two food products, cereals and meat/dairy, and transport fuel, are modeled using a Cobb-Douglas function. They are exogenously driven by population and per capita income. We distinguish between meat/dairy and cereals to account for the change in dietary habits. Meat/dairy products include all types of meat and dairy such as milk and butter. Cereals include all grains, starch crops, sugar, sweeteners and oil crops. The demand for fuel is in Vehicles Miles Traveled (VMT).

Since land quality varies by geographical region, we disaggregate land into three classes. Each land class (or land quality) is based on their climate and soil characteristics ([Eswaran, Beinroth and Reich 2003](#)) and may be allocated either to crops or to first or second generation

biofuels.<sup>1</sup> Land may be expanded by converting lands not yet cultivated, which may be of class 1, 2 or 3, one being the highest quality. The initial stock of available land is given. At each period, new land may be brought under cultivation. The cost of land is endogenously determined by the shadow price of the land constraint in the model. The cost of converting new land is assumed to be increasing and convex with respect to the acreage converted. We adopt the same functional form as in [Gouel and Hertel \(2006\)](#). Land is brought into cultivation when the land rent exceeds the cost of conversion.<sup>2</sup>

Total area available is the sum of land currently under farming and land under other uses, such as pasture and forests. The initial global endowment of agricultural land is 1.5 billion hectares (FAOSTAT). About 1.6 billion hectares of additional land are available for cropping possibly at a higher cost of production ([FAO 2008](#)). Most fallow land is located in South America and Africa. Land under the Conservation Reserve Program (CRP) is assumed to be available for crop production in the US. Food production is assumed to exhibit constant returns to scale for each land class. Hence, regional food supply is just yield times the land area. Improvements in agricultural productivity are allowed to vary by region and land category. Crops are transformed into cereals and meat/dairy at cost (final goods).

We consider a representative biofuel in each region. In the US, 94% of biofuel production comes from corn ethanol, while 76% of EU production is biodiesel from rapeseed ([EIA 2011](#)). In the MICs, 94% of biofuels are produced from sugar cane. In the Other HICs and LICs, biofuel production is marginal. Second generation biofuel technologies are assumed to be available only in the US and EU. Cellulosic ethanol in the US and Biomass-to-Liquid diesel (BTL) in the EU have been identified as among the most competitive second generation biofuels. Even if they are less land consuming, their production cost is higher than that of first generation biofuels. [Table 1](#) reports energy yields and production costs for first and second generation biofuels. First generation

<sup>1</sup> Crops are then transformed into cereals or meat/dairy products. Of course, land could also be left fallow.

<sup>2</sup> We assume that emissions from land conversion and benefits from biofuel production are instantaneous, meaning that there is no time lag between planting and harvesting. This may be a reasonable approximation since crops like corn and sugarcane grow within a year or less.

**Table 1. Characteristics of First and Second Generation Biofuels by Region**

	First-generation biofuels		Second-generation biofuels	
	gal/ha	US\$/gal	gal/ha	US\$/gal
<b>US</b>	800	1.01	1,800	1.75
<b>EU</b>	400	0.55	2,000	2.25
<b>MICs</b>	1,700	0.57	NA	NA

Notes: NA implies that the technology is not yet available. Source: Biofuel yields (FAO 2008; IEA 2009) production costs (FAO 2008; Eisentraut 2010; IEA 2009).

yields differ by land quality. However, yields of second generation biofuels are assumed to be uniform across land classes since second gen crops are less demanding in terms of land quality (van den Wall Bake *et al.* 2009).

The oil market is modeled independently. The initial stock of oil (including unconventional oils) available for transportation equals 154 billion gallons (World Energy Council 2010).<sup>3</sup> To take into account the heterogeneity of oil reserves, extraction costs depend on the cumulative quantity of oil used (Nordhaus and Boyer 2000). Oil is then transformed into gasoline or diesel.<sup>4</sup> We model the production of energy using a CES specification (Ando, Khanna and Taheripour 2010). Fuel is a blend of gasoline and biofuels which can be first or second generation. The elasticity of substitution is taken to be 2 for the US and 1.55 for the EU, respectively (Hertel, Tyner and Birur 2010).

Even though several countries (such as China and India) have adopted biofuel policies, we focus on US and EU mandates. US production is supported by a tax credit to blenders of 45 US cents per gallon. This credit is expected to be withdrawn at the end of 2012.<sup>5</sup> A 2.5% ad valorem tariff and a per unit tariff of 54 US cents per gallon have been established to protect domestic production. In this version of the paper, trade barriers are still in

place.<sup>6</sup> Finally, a \$1.01/gallon subsidy is provided for second generation biofuels. However, the bigger push has come from renewable fuel standard (RFS) mandates which were initially set at 7.5 billion gallons of biofuel by 2012, reaching 36 billion gallons in 2022. Ethanol use is expected to increase at least until 2015, while the bulk of future growth in biofuel supplies is likely to come from second-generation biofuels (cellulosic ethanol). The European Union also employs a mix of policies to encourage biofuel use (Kojima, Mitchell, and Ward 2007). EU states have tax credits on biodiesel ranging from 41-81 cents. We include an average tax credit of 60 cents for the EU as a whole. In addition, there is a 6.5% ad valorem tariff on biofuel imports. According to the EU 2009 Directive the biofuel share in transportation fuel is slated to increase from current levels of 4% to 10% by 2020 (European Commission 2009). EU mandates have no minimum requirement on second generation biofuels.

Data on carbon footprints are taken from Chakravorty *et al.* (2012). The model also captures indirect carbon emissions. We assume that respectively, 300 and 500 tons of CO<sub>2</sub> are released per hectare from land classes 2 and 3 immediately after land conversion (Searchinger *et al.* 2008). Consumers derive utility from consumption of transportation energy and food. Consumer and producer surplus is maximized given fixed endowments of land. Gasoline and biofuels are imperfect substitutes; hence, the fuel composition depends upon their relative price. Without regulation, biofuels become competitive as oil stocks deplete and oil prices increase. The competitiveness of biofuels depends upon the demand for food products. Under regulation, the mandate imposes a minimum use of biofuels while the carbon tax increases the price of all fuels (gasoline and biofuels) depending on their carbon content.

## Simulations

In the Baseline scenario (BASE), we suppose that the US and EU mandates are not implemented. Next we examine the effects of two policy scenarios on the world food and energy markets. In the Mandate scenario (called *Mandate*), the US and EU biofuel mandates are

<sup>3</sup> Oil is also an input in sectors other than transportation, such as in chemicals and heating. IEA (2011) estimates that about 60% of crude oil is used in transportation. So we only consider 60% of total oil reserves as the resource stock available for transport.

<sup>4</sup> One gallon of oil yields 0.47 gallons of gasoline and 0.25 gallons of diesel (USD OE). We assume that these coefficients are uniform across regions even though refineries may exhibit varying efficiencies in converting crude oil into petroleum products. For each region, we consider a representative fuel, e.g., gasoline in the US and diesel in EU. However, in the paper we use the term "gasoline" for all petroleum products.

<sup>5</sup> Beyond 2012 this tax credit equals zero in our model.

<sup>6</sup> We ran the model after removing the import tariffs, but the results did not change appreciably.

**Table 2. Effects of Biofuel Policies on Food and Fuel Markets (year 2022)**

	Baseline	Mandate	Carbon
<b>Prices</b>			
Gasoline price (\$/gal)	2.51	2.50	2.52
Biofuel price (\$/gal)	2.04	2.25	2.27
Food price (\$/ton)	638	744	743
<b>Gasoline use (billion gallons)</b>			
US	123	117	116
EU	54	51	50
MICs	152	153	154
<b>First gen biofuel use (billion gallons)</b>			
US	7.9	15.0	15.0
EU	1.0	1.8	1.8
MICs	8.6	7.2	7.0
<b>Second gen biofuel use (billion gallons)</b>			
US	0.0	21.0	21.0
EU	1.7	3.9	4.0
<b>Biofuel/gasoline share (%)</b>			
US	6.0	23.0	23.0
EU	2.9	10.0	10.0
MICs	5.5	4.5	4.0
<b>Biofuel net exports (million gallons)</b>			
US	-597	-1,125	-1,200
EU	-4	-90	-91
MICs	+1,574	+2,030	+2,035
<b>Land cultivated (million hectares)</b>			
World	1,754	1,825	1,828

Note: "Food" implies a weighted basket of commodity prices.

implemented. In the Carbon scenario (*Carbon*), the above mandates are combined with a carbon tax policy. We impose a time-varying carbon tax of \$20/ton CO<sub>2</sub> in 2010, gradually increasing to \$39/ton in 2022 (EIA 2009). This tax is based on the allowance price under the cap-and-trade provisions of the Clean Energy Security Act. In what follows, we analyze the results only for the year 2022. The effect of these policies on food and fuel markets are reported in table 2, while table 3 discusses their impact on direct and indirect GHG emissions.

#### Baseline scenario

In the absence of any regulation, biofuel consumption decreases in the US and EU. It is about 7.9 billion gallons (US) and 2.7 billion gallons (EU) in 2022. The respective shares of biofuels in blending fuel are 6% and 3%. The only region where the production of biofuels is steadily increasing without mandates is the MICs. We do not observe any second generation biofuel consumption due to their high costs of production in the US. However, more than 50% of biofuels demand is met by

**Table 3. Effects of Biofuel Policies on GHG Emissions (in 2022, billion tons CO<sub>2</sub>)**

	Baseline	Mandate	Carbon
<b>Direct carbon emissions</b>			
US	2.04	2.01	2.00
EU	0.86	0.84	0.83
World	6.35	6.32	6.31
<b>Indirect carbon emissions</b>			
World	7.25	11.70	11.75
<b>Total emissions</b>			
World	13.60	18.02	18.06

second-generation biofuels in the EU in 2022 (see table 2). In this scenario, 20 billion gallons of biofuels are used in aggregate globally.

The consumption of transport fuels in the HICs is quite stable. But it increases sharply in the developing countries, up by about 60% to 2022. As a result, MICs and LICs become the world's largest direct carbon emitters by 2030. Because of the combined effect of a rise in population and in per capita income, food consumption in MICs and LICs also goes up by 20%. To meet world food demand, 74 million hectares of land are brought into cultivation by year 2022, which releases significant indirect carbon emissions into the atmosphere. Adding direct and indirect carbon emissions, we conclude that aggregate world emissions almost double in this period (2007-2022).

#### Carbon emissions

A major goal of the mandates is to reduce carbon emissions. In the US and the EU, direct carbon emissions decrease by 1.5% and 2% respectively (*Mandate* scenario, see table 3). In both countries, gasoline consumption decreases in favor of biofuels. However, aggregate fuel consumption rises, hence, GHG emission reductions are fairly modest.

However, GHG emissions decline when the mandates are combined with a carbon tax. The respective decrease in carbon emissions in the US and EU is 2.0% and 3.5% (*Carbon* scenario, see table 3). The carbon tax causes a rise in the price of gasoline and biofuels depending on their carbon intensities per gallon (see table 2). Beyond creating incentives to switch to the less GHG-intensive fuel, the tax raises the price of VMT, and hence reduces VMT consumption and GHG emissions. In EU, VMT consumption decreases by 2.12% while it is almost stable in the US.

Under both scenarios, direct carbon emissions in the rest of the world rise, the increase being more significant under the *Carbon* scenario. Due to the mandate, the world biofuel price goes up by 10% because the mandates force more land into cultivation, which are inferior quality, thus raising the cost of production. Consumers in the rest of the world respond by switching towards gasoline. In the MICs, the share of biofuels decreases from 5.5 % under the *Baseline* scenario to 4.5 % under the *Mandate*. Gasoline consumption decreases by 1% while biofuel use is reduced by 16%. As a result, direct carbon emissions in the rest of the world increase by less than 1%. Under the *Carbon* scenario, the gasoline price increases while it decreases under the *Mandate* (see table 2). As a result, the switch towards more gasoline and less biofuels is more pronounced under the carbon tax.

None of the instruments we model succeed in significantly reducing indirect carbon emissions. When the mandate is implemented in land scarce countries such as the US or the EU, the biofuel target is met by increasing the imports from land abundant MIC nations.<sup>7</sup> Under *Carbon*, indirect carbon emissions are higher than under the *Mandate* scenario. The carbon price instrument improves the competitiveness of sugar-cane ethanol because gasoline is more carbon-intensive and therefore becomes relatively expensive. Moreover, ethanol produced in the US gets taxed while imports do not, since they originate from other countries. Compared to the *Mandate*, US biofuel imports from MICs increase. As a result, area converted to cropping goes up by an additional 5 million hectares. Indirect and total emissions are highest under the *Carbon* scenario because deforestation in other countries is not subject to the carbon tax. As shown in table 3, the mandates also increase global emissions relative to the no mandate case.

### Welfare analysis

We calculate regional and world welfare gains and losses by computing surplus in the food and fuel markets. The absolute changes in surplus under biofuels policies compared to the no-intervention case are reported in table 4. We first compute the tax-subsidy instrument to achieve the mandated biofuel use. When

**Table 4. Welfare Gains and Losses in Year 2022 under Different Biofuel Policies (Billions, constant 2007 dollars)**

	Mandate	Carbon
<b>Food sector</b>		
US	154	155
ROW	-450	-449
<b>Energy sector</b>		
US	51	-23
ROW	-10,848	-11,325
<b>Tax revenue</b>		
US	-90	-10
<b>External costs</b>		
US	0.39	0.39
ROW	-173	-225
<b>Net welfare change</b>		
US	115	122
ROW	-11,034	-12,160
World	-11,002	-11,002

*Note:* The numbers reported are the difference between the surplus under the biofuel policy scenario relative to the Baseline. The tax revenue is calculated differently under each scenario. Under *Mandate*, it is the difference between the import tariff revenue and the cost of biofuel subsidies. Under *Carbon*, it is the import tariff revenue plus the carbon tax revenue minus the cost of biofuel subsidies.

the mandate is accompanied by a carbon tax, the biofuel tax credit is reduced from \$1.74/gal under *Mandate* to \$1.54/gal under the scenario *Carbon*. Under the *Carbon* scenario, because gasoline is the dirtier fuel, its price increases by more than that of ethanol, hence a lower subsidy is required to enforce the mandate.

The impacts of biofuel policies are regressive, with richer regions less impacted and the poorest hit the hardest under both scenarios. However, total US welfare increases in both cases (see table 4). In response to the US mandate, world food prices increase by 17% and world biofuel prices rise by 10%, which benefits the US agricultural sector. Surplus in the fuel market goes up slightly. The mandate causes a decrease in the fuel blend price and an increase in consumption. It thus benefits US consumers. However, US welfare gains are mostly eroded by the cost of biofuel subsidies required to achieve the target. The cost of the subsidies net of tariff revenues totals \$90 billion dollars. The bulk of the subsidy payments are made in order to encourage the use of second generation biofuels. The benefit from the decrease in carbon emissions is almost insignificant (see table 4). When the mandate is combined with a carbon tax, the US agricultural sector also experiences a slight increase in welfare compared to the *Mandate* scenario. However, the total surplus in the fuel market decreases compared to the *Baseline* scenario in response to

<sup>7</sup> Among MICs, Brazil benefits in the export market because it has low biofuel production costs.

the rise in the price of the fuel blend. The loss from subsidies is reduced to \$10 billion dollars because of the larger revenue from the carbon tax (see table 4).

The largest loss in welfare is observed in the MICs and LICs. A rise in energy prices leads to a loss of surplus in the energy sector. Surplus from food also goes down. In the MICs and LICs, a relatively high share of income is spent on food; hence, any rise in food prices impacts consumer surplus significantly. This channel is all the more important since price elasticities for food products are low at lower income levels. The loss in welfare due to carbon emissions is substantial in the rest of the world. World surplus relative to baseline does not change significantly across the different biofuel policies. However, the composition of surplus is quite different. Under the mandate, the US and EU consumers are relatively better off, while under the mandate coupled with a carbon tax, consumers in the US and EU fare poorly. Consumers in developing countries are adversely affected by the mandate and are slightly less worse off under the combined mandate plus tax policy.

## Conclusion

We analyze the effects of biofuel policies on carbon emissions and welfare. The policies considered include the US and EU mandates accompanied by a biofuel subsidy or by a carbon tax. GHG emission reductions are quite modest in size when biofuel mandates are implemented. The price of blending fuel decreases in the regulated countries, which increases energy use and thus, GHG emissions do not decline. When the mandate is accompanied by a carbon tax, the price of gasoline and biofuels both increase depending on their respective carbon intensities. By raising the cost of both fuels, the carbon price instruments lead to a rise in the price of the fuel blend and a decrease in carbon emissions. However, the domestic reduction in GHG emissions achieved by the biofuel policies (mandate plus carbon tax) is eroded by larger indirect carbon emissions, in other countries. Indirect carbon emissions are higher when the mandate is implemented along with a carbon tax. The carbon tax increases the competitiveness of imported biofuels from MICs. As a result, more marginal lands are brought into cultivation. In terms of welfare effects, poorest regions are most impacted by the regulation in the US

and in the EU. Consumer welfare is adversely affected by an increase in food prices. In addition, they suffer from a significant increase in indirect carbon emissions.

Our analysis can be improved to determine the optimal tax in the transportation sector. In future work, the disutility of congestion and the external costs of accidents could be included in our model. According to Parry and Small (2005), the most important externality is traffic congestion. The fuel tax turns out to be a rather poor means of controlling distance-related externalities like congestion because it is indirect. In response to a rise in the fuel tax, consumers respond by purchasing more fuel-efficient vehicles rather than driving them less. A direct tax on vehicle miles traveled (VMT) may perform better. Therefore, an optimal policy for transportation may consist of a direct tax on vehicles miles traveled plus a carbon tax, which could be modeled in future work.

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