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Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis

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Abstract

The rapid growth of biofuels production, particularly in the United States, the EU, and Brazil, has had important implications for the global livestock industry—both by raising the cost of feed grains and oilseeds and by forcing onto the market a large supply of biofuel by-products, most of which end up in livestock feed rations. This article investigates the impact of an expanding biofuels industry on the mix and location of global livestock production. Surprisingly, we find that growth in the U.S. and EU biofuels industries results in larger absolute reductions in livestock production overseas than in those regions, due to the international transmission of grains prices which is offset locally by the lower cost of by-products. We also find that nonruminant production is cut more than ruminant livestock, because it is less able to use biofuel by-products in its feed rations. Implementing biofuel mandates increases cropland area, a large portion of which is estimated to come from reduced grazing lands. The biofuel producing regions are expected to reduce their coarse grains exports and increase imports of oilseeds and vegetable oils, while they increase their exports of processed feed materials. In sum, biofuel mandates have important consequences for livestock as well as crops, with net effects influenced by the important role of by-products in substituting for feedstuffs.

JEL classifications: C51, C68, Q13, Q43, Q49

Keywords: General equilibrium; Livestock, Feed rations; Biofuel mandate; Land use

1. Introduction and literature review

The global biofuel industry has experienced a period of extraordinary growth in recent years and is expected to continue to expand in the future. This has important consequences for the farms producing biofuel feedstocks, such as corn, sugarcane, and oilseeds, and most studies to date have focused on these crop sector impacts as well as land cover changes (Birur et al., 2007; Hertel et al., 2010; Searchinger et al., 2008; Taheripour et al., 2010). However, the biofuel boom has significant implications for the global livestock industries as well. The purpose of this article is to delve more carefully into the impacts of expanding of biofuel production for the global livestock industries and their links to other industries and markets.

The most obvious consequence of large-scale biofuel production for the livestock industry is higher crop prices with attendant increases in input costs. Biofuel production also raises returns to cropland, which, in turn, encourages conversion of some pastureland to crops, thereby further increasing production costs for ruminant livestock. On the other hand, biofuels are produced in conjunction with valuable by-products that can be used in the livestock industry as animal feeds and can substitute for the higher priced crops in animal rations. Production of biofuel by-products such as Distillers Dried Grains with Solubles (DDGS) and oilseed meals have significantly increased in recent years following the boom in biofuel production.

However, not all livestock industries are well-placed to capitalize on the increased availability of such by-products. Ruminants (dairy and beef) are better able to make use of DDGS in their feed rations and are therefore better positioned to gain from increased DDGS availability in the wake of ethanol production. Increased availability of oilseed meal in the wake of oilseed crushing for biodiesel benefits a wider range of livestock, including nonruminants.

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Note: Data and model code for replication of this article's main results are archived on the GTAP website at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3194.

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Biofuel by-products represent an important component of biofuel industry revenues. If the livestock industry could not absorb these by-products, their prices would fall sharply, thereby limiting expansion of the industry. In addition, both biofuel and livestock industries compete for crop inputs. The interactions between these industries and the rest of the economy become even more complicated when we take into account the linkages with energy markets. For this reason, a formal model is required in order to provide a comprehensive evaluation of consequences of biofuel production for the global livestock industry.

The United States and EU have developed their biofuel industries significantly during the past decade. The U.S. ethanol production has increased from 1.1 billion gallons in 2002 to 10.6 billion gallons in 2009. The United States has now surpassed Brazil as the world's leading producer of ethanol. During the same time period the EU biodiesel production has increased from about 0.3 billion gallons to 2.7 billion gallons. The U.S. and EU have defined programs to increase their biofuel production and consumptions in the future. These programs could push the global biofuel industry beyond its current position, although possible barriers have developed in both regions—the "blend wall" in the United States and environmental issues in the EU.

Several aspects of expansion in biofuel production have been examined in the literature. Some studies have used partial equilibrium models and examined impacts of biofuels on grain and livestock industries. For example, Elobeid et al. (2006) and Tokgoz et al. (2007) have studied impacts of U.S. ethanol production on grain and livestock industries in the United States using partial equilibrium models. The former did not take into account the possibility of using ethanol by-products as animal feed and hence its results are not likely to be accurate. However, the latter did include distillers grains in its analysis and reports moderate effects of ethanol production on the U.S. livestock industry. Both articles disregard the land market and the competition between crop, livestock, and ethanol industries for land. They also ignored the EU biofuel mandates and paid no attention to the interactions between the U.S. and EU mandates and their implications for the global livestock industry. We will incorporate these factors into our analyses.

Many studies have examined the use of biofuel by-products and their suitability for different types of animal species (Anderson et al., 2006; Bregendahl, 2008; Daley, 2007; Klopfenstein et al., 2008a, 2008b; Schingoethe, 2008; Shurson and Spiehs, 2002; Stein, 2008; Whitney et al., 2006). In general, these articles indicate that distillers grains can be introduced in animal feed rations more extensively, compared to the existing feed rations, at different rates across different types of species. A group of studies has also estimated huge potential markets for these products based on purely theoretical feed rations (Cooper, 2005; Dhuyvetter et al., 2005; Fox, 2008; Paulson, 2008). In this context, several articles calculated the displacement ratios between DDGS and other feed ingredients for different types of animal species. For example, Arora et al. (2008) have calculated displacement ratios for different animal species using experimental feed rations, although they ignore the impact of changes in feed prices on the optimal mix of feed ingredients.[1]

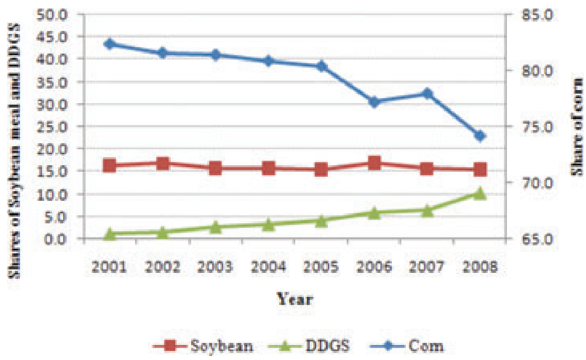
Finally, several studies have used Computable General Equilibrium (CGE) models and addressed the economy-wide consequences of producing biofuels at a large scale (Banse et al., 2007; Birur et al., 2007; Dixon et al., 2007; Reilly and Paltsev, 2007). These articles have all ignored the role of by-products resulting from the production of biofuels; hence, they do not provide an accurate evaluation of economic consequences of biofuel production, in particular for the livestock industry, which is the main user of biofuel by-products.

In a recent work, Taheripour et al. (2010) introduced biofuel by-products into a special purpose version of the Global Trade Analysis Project (GTAP) model (Hertel, 1997) of the global economy and have shown that incorporating biofuel by-products considerably dampens the impacts on land use and commodity prices in the face of 2015 U.S. and EU biofuel mandates (we will henceforth refer to this article as THTBB). THTBB included the livestock industries in their model. However, THTBB does not analyze the link between agriculture, livestock, vegetable oil, food, and biofuel industries in the presence of biofuel by-products. As a result, one cannot see differential consequences of biofuel production for these activities.

The current article enriches our understanding of the impacts of biofuel mandates in the United States and the EU on the global structure of the livestock industry. We adopt as our starting point for this article the work reported in THTBB, and we extend it to highlight the impacts of biofuel mandates for the global livestock industries. The framework that we develop in this article is global in scope and links global production, consumption, and trade. In addition, it carefully links energy, biofuel, and agricultural markets. Since biofuel, crop, and livestock industries compete through the land market, the model links these activities through the land market as well. Furthermore, biofuels by-products, which can be used in animal feedstuffs, bridge these industries and highlight the nature of competition among these industries.

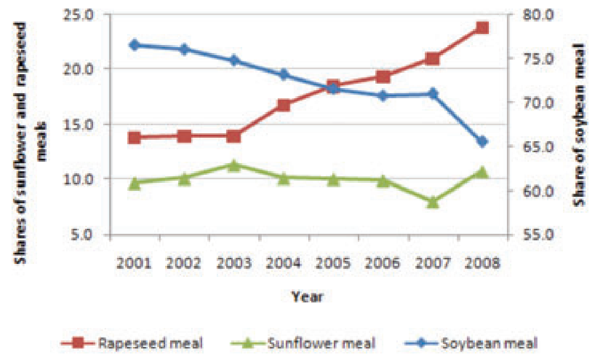
The treatment of livestock feed demand in this article is particularly important, as this is the vehicle for linking the availability of by-products, as well as the higher feed prices induced by biofuels to the livestock industries on a global scale. More specifically, instead of simply assuming a given rate of feedstuff offset due to the availability of by-products, we permit

[1] In calculating these displacement ratios, they consider impacts of displacing corn for distillers grains on the composition of feed rations and weight gains of animal species during their production lifecycles. These authors indicate that 1 kg of distillers grains could displace 1.19 kg corn and 0.06 kg urea used in the beef cattle sector of the United States. Their displacement ratios for the U.S. dairy sector are 0.73 kg corn and 0.63 kg soybean meal and for the swine industry are 0.89 kg of corn and 0.095 kg of soybean meal. Several factors such as changes in the relative prices of feed ingredients, livestock prices, and the mix of animal species held by the livestock industry could alter these displacement ratios. For example, Fabiosa (2009) has shown that 1 kg of DDGS could displace between 0.77 kg and 0.94 kg of corn in the swine feed rations, if we take into account impacts of changes in the feed prices on the optimal mix of feed ingredients.



Source: Prepared based on data obtained from: http://www.fas.usda.gov/psdonline.

Fig. 1. Quantity shares of major feedstuffs in the U.S. livestock feed.



Source: Prepared based on data obtained from http://www.fas.usda.gov/psdonline.

Fig. 2. Quantity shares of major oilseed meals in the EU livestock meal.

Source: Prepared based on data obtained from: http://www.fapri.iastate.edu/outlook/.

Fig. 3. Price of rapeseed meal relative to the prices of soybean meal and wheat in the EU.

feed intensities to vary with relative prices to reach zero profit condition for the livestock industry. The underlying elasticities of substitution are calibrated based on observed behavior over the 2001–2006 historical period. To the best of our knowledge other economy-wide CGE models do not have a comparable capability. It is this capability that allows us to discern the differential impact of biofuels on livestock sectors across different countries.

2. Historical links between biofuels, feeds, and livestock

The literature review presented in the first section asserts that the livestock industry could use biofuel by-products to partially offset the higher costs consequences stemming from higher crop prices. Historical observation confirms this statement. During the time period of 2001–2008, U.S. DDGS outputs have increased by 19.9 million metric tons (from 3.1 to 23), and exports have increased by 3.7 million metric tons (from 0.8 to 4.5). And, as shown in Fig. 1, the quantity share[2] of corn in the main feedstuffs (corn, soybean meal, and DDGS) used in the U.S. livestock industry has declined from 82.4% to 74.2% during the time period of 2001–2008. On the other hand the quantity share of DDGS has increased from 1.3% to 10.3%. During the same time period, the U.S. livestock industry has effectively replaced 15.5 million metric tons of corn with 16.2 million metric tons of DDGS. These figures generate a historical displacement rate of 0.95 kg of DDGS per kg of corn for this period. Fig. 1 also shows that the share of soybean meal in U.S. feedstuffs has remained around 15%, which suggests that DDGS has not led to the displacement of soybean meal consumption in this time period. However, it is difficult to conclude that DDGS does not displace soybean meal consumption at the farm level, based on this aggregate observation, because the composition of livestock industry has changed over this time period as well.

[2] Quantity shares reported in this section are obtained from quantities of feedstuffs used in livestock industry in metric tons. These quantities are available at: http://www.fas.usda.gov/psdonline.

Fig. 2 depicts the quantity shares of rapeseed, sunflower, and soybean meals in the meals used by the EU livestock industry during the time period of 2001–2008. This figure shows that the share of rapeseed meal (the main by-product of producing biodiesel from rapeseed) has increased from 13.8% to 23.8% in this time period, while the share of soybean meal has fallen from 76.5% to 65.5%. During the same period, production of rapeseed meal—a by-product of rapeseed crushing for oil to be used in production of biodiesel—within the EU has doubled, rising from 6 to 10 million metric tons.

These changes in feed shares have been induced by changes in relative prices of these by-products, which have declined, relative to other feedstuffs, resulting in their increased importance in the feed mix. For example, in the United States, the average price of DDGS increased 46% during 2001–2008, while the average price of corn, a major feedstuff, increased 84% during the same period. Due to the boom in biodiesel production from rapeseed in the EU, the price of rapeseed meal has fallen relative to the prices of soybean meal and wheat (a major feedstuff in the EU) during the same time period, as shown in Fig. 3. This suggests that biofuel by-products can help to offset some of the adverse cost implications of the biofuels boom for the livestock industry. What implications have these important linkages had for the global structure and composition of the livestock industry? How is this likely to evolve as countries move to fulfill even more ambitious biofuel targets? To answer these questions we need an analytical framework that is multi-sector and global in scope. The next section introduces our modeling framework.

3. Analytical framework

In this section, we develop our methodology to explain the links among crops, biofuels, livestock, food, and feed industries and the competition between these industries in the primary input markets for land, labor and capital.[3] The competition for land is a key issue in this article. Hence, we highlight the consequences of biofuels production for land from different angles. Consequences of biofuel production for the capital and labor markets are also important topics, but they are not in the core of our analyses in this article.

A stylized representation of the links between food, feed livestock, and biofuel industries and their competition for land is provided in Fig. 4. There are four panels in this figure—each successive one illustrating an additional linkage that we will take into account. The first panel of this figure depicts an economy with no biofuels such that the crop industry uses land and supplies material to the food, feed, and livestock industries. The direct link between the crop and livestock industries represents nonprocessed crops used by the livestock industries. In addition, the livestock industries take feedstuffs from the feed and food industries (typically food waste and by-products) and use pastureland as an input as well.[4]

In panels 2, 3, and 4 we introduce biofuels into the economy. In the second and third panels we assume that biofuel production does not reduce demands for food. Hence, we ignore the consumption side of the economy in these two panels. The second panel introduces the biofuel industry into the economy, while ignoring the role of biofuels by-products. In this case, in the absence of adjustment in food consumption, if the size of biofuel industry is large, the demand for crop feedstocks to support biofuel production may have a very large impact on crop prices. This increases the demand for land and may induce the conversion of forest and pastureland to crop production. If that happens, then the livestock industry needs more crops and processed feedstuffs to meet the demand for its products. Recall that we assume biofuel production does not reduce food consumption. This could elevate forest conversion to crop production.

Panel 3 takes into account the biofuel by-products. In the presence of these by-products, the biofuel industry sends its by-products to the livestock industry. The livestock producers can substitute these by-products for crops and use them in their animal feeds. This directly reduces the livestock demand for crops. This reduction in the demand for crops will reduce conversion of land to crop production. Including biofuel by-products will reduce the prices of crops and livestock products, compared with the cases of panel 2.

The final panel of Fig. 4 introduces consumer demand and trade into the picture. Up to this point we were assuming that biofuel production does not affect the final demand for crops and food products. In the real world, production of biofuels from agricultural resources raises the prices of crops and food products. In response to higher prices, *ceteris paribus*, the domestic and foreign users will reduce their demands for crops and food products (including processed livestock products). This causes a drop in the demand for land compared to the case of panel 3 and mitigates the pressure on land conversion.

While the stylized analytical framework demonstrated in Fig. 4 still represents a rather simple economy, the numerical modeling framework used in this article (GTAP) covers the full range of economic activities. In addition, the model consists of many countries, including nonbiofuel and biofuel producing regions. The biofuel producers are mainly United States, EU, and Brazil. Brazil has the most well-established biofuel program in place, while the United States and EU have announced mandate programs to increase production and consumption of biofuels in the future. We use our model to study the global economic and land use consequences of these mandates, in particular for the livestock industry.

In Fig. 4, we intentionally ignore the link between biofuels and petroleum products to generate the stylized framework. In reality in the U.S. ethanol is mainly used as an additive in gasoline production process (E10) and a small portion of that is used by final consumers in the form of E85. In Brazil, consumers use ethanol in flexfuel vehicles. Biodiesel is also sold as a final fuel to final consumers in many countries. Our model distinguishes between intermediate (additive) and final uses of biofuels (for details see Birur et al., 2007). It is important to note that biofuel industries also are tied to the world market. Currently, Brazil exports ethanol to several countries, and EU members import palm oil from Malaysia and Indonesia, in addition to their ethanol imports. Our model covers the trade of biofuels as well.

In this article, we develop several experiments, which characterize different aspects of economies presented in successive panels of Fig. 4, thereby permitting a rigorous decomposition of the role of by-products and the competition for land among biofuel, crops, and livestock industries in the economic and environmental analyses of biofuels and biofuel policies. These experiments also allow us to analyze the impacts of the U.S. and EU biofuel mandates for the key industries discussed above, in particular livestock.

4. Modifications in GTAP-BIO model and its data base

To develop the experiments mentioned earlier, we extend the work reported in THTBB in several directions. First, we

[3] In general, in the GTAP modeling framework, there is competition between different industries to use primary inputs such as land, labor, and capital. In this framework producers select an optimal mix of primary inputs to maximize their profits, according to the prices of inputs.

[4] Note that our data base indicates that in some regions the food industry is taking tiny amounts of inputs from the feed industry, we ignored this link in Fig. 4.

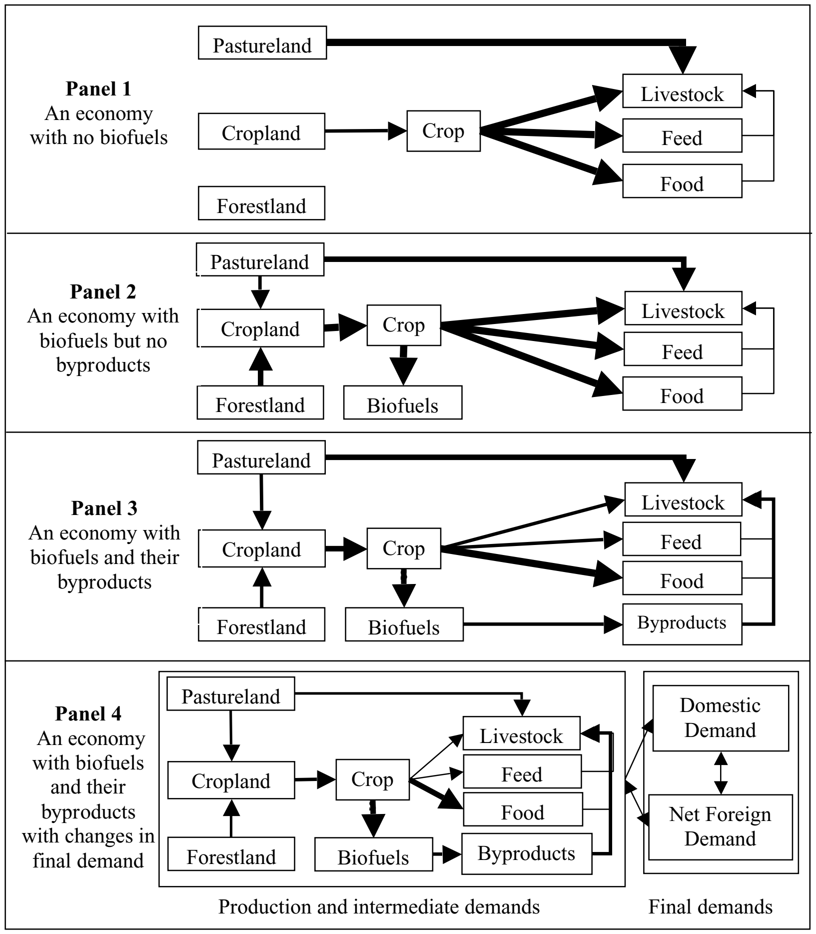


Fig. 4. Links between crop, food, feed, livestock, and biofuel industries and their competition for land in the presence and absence of biofuel by-products.

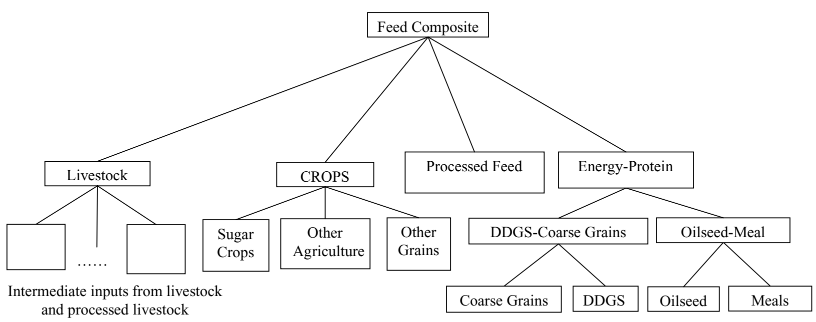


Fig. 5. Structure of nested demand for feed in livestock industry.

made a major revision in the demand side of the model for animal feeds. THTBB used a two level nesting demand structure for animal feeds. They first consider substitutions between coarse grain and DDGS and between processed feed and oilseed meals. Then they directly combine the mixes of (DDGS–Coarse grains) and (Oilseed meals–Processed feed) with other feed ingredients. Their nesting structure is an appropriate way to model the demand for feed in a CGE framework, but it ignores complementary relationships between the protein and energy feed ingredients. We extend their feed structure to be able to bundle homogeneous feed ingredients together and then apply appropriate elasticities of substitution among them. Here, we define a three level nesting structure for the demand for feeds in the livestock industry. Fig. 5 represents this nesting structure. Following THTBB, at the lower level of this nesting structure DDGS and coarse grains are combined to create an energy feed composite. Unlike THTBB, which combine oilseeds with processed meal, we combined oilseeds and oilseed meals at this level to create a protein feed composite. At a higher level the protein and energy feed ingredients are combined into an energy-protein composite input. At this level other crops also are bundled together. The livestock industry purchases some inputs from processed livestock industry (mainly waste items) as well. These materials are bundled together at the second level too. Finally, all feed ingredients are combined to create a feed composite. It is important to note that in some regions (e.g., United States) corn is crushed to produce corn oil or other products such as corn sweeteners. In these regions a small portion of the aggregated oilseed meals in the GTAP data base is corn gluten feed, which is mainly an energy feed.

Following Keeney and Hertel (2005) we used 0.9 for the elasticity of substitution at the top level of the feed structure. These authors derived this figure from a matrix of feed price elasticities obtained from an empirical estimate of demands for feed items. They aggregated the off-diagonal elements of this matrix using shares obtained from GTAP data base. This aggregated elasticity matches with the elasticity of substitution which we need at the top level of the feed structure presented in Fig. 4. We assigned values to the other composites of the feed nest through a calibration process explained later.

At the second level, the elasticity of substitution between the energy and protein feedstuffs plays an important role. In general, there is a complementary relationship between these feed items (i.e., a zero elasticity of substitution). However, we applied a small elasticity of substitution between these two groups of feedstuffs for two main reasons. According to Arora et al. (2008) and Fabiosa (2009), DDGS could displace a small portion of meals. This suggests using a small elasticity of substitution between the energy and protein inputs. On the other hand as noted earlier, in the GTAP data base a small portion of oilseed meals is corn gluten feed, which is mainly a source of energy in animal feed rations. This supports a small elasticity of substitution between the energy and protein feedstuffs as well. Keeney and Hertel (2005) have considered 0.15 for the elasticity of substitution between energy and protein feed ingredients in the absence of DDGS. However, in our historical calibration process, explained later on in this article, we learned that in the presence of DDGS a higher elasticity of 0.3 is required to match our simulation results with the observed trends in the feed composites of U.S. and EU livestock industries during the time period of 2001–2006.

At the second level of the nest, for the composite of other crops and composite of processed livestock inputs we applied elasticities of substitution of 1.5 to facilitate substitution between the homogenous feed items included within each of these two groups.[5] We selected this figure along with the elasticities of the bottom of the nest through the calibration process explained further.

At the bottom of the nest, oilseed and oilseed meals are close to perfect substitutes. On the other hand, corn and DDGS are also close to perfect substitutes. This suggests assigning high elasticities of substitution to the composites of oilseed–oilseed meals and coarse grain-DDGS. In the course of our calibration process, we learned that assigning very high elasticities of 20 and 25 to the former and latter composites—uniformly across all types of animal species—will allow us to match our simulation results with the observed changes in the prices of corn, oilseeds, and oilseed meals in the United States and EU during the time period of 2001–2006, when ethanol and biodiesel production was rising. However, since animal species are different in their ability to digest DDGS, we applied values of 30, 25, and 20 for the elasticities of substitution between coarse grains and DDGS in the meat ruminant, dairy farms, and nonruminant feed structures, respectively. These figures generate simulation results very similar to the uniform value of 25.

Here, we briefly examine the results of the calibration process mentioned above to test the consistency between the model results and the historical observations on the changes in feed composite of the U.S. and EU livestock industries during the time period of 2001–2006. To accomplish this task we examine changes in the cost shares of coarse grains, other crops, DDGS, and meals in total feed costs. These cost shares are calculated at constant prices and therefore their changes reflect changes in feed intensity (see Appendix Table B1). This table indicates that the cost share of DDGS increased across all types of livestock industries, in particular in the meat ruminant industry, in the United States during the time period of 2001–2006, while the cost share of coarse grain decreased. The cost share of meals remained relatively constant in this region. Table B1 also indicates that in the EU region the cost shares of DDGS and meals increased, while the cost share of coarse grain and other crops (mainly wheat) decreased. These changes are consistent with the historical changes in feed ingredients of the U.S. and EU livestock industries.

Taheripour et al. (2007) introduced biofuels into the version 6 of GTAP data base (Dimaranan, 2006). We will refer to this data base as GTAP-BIO. THTBB has made two major modifications into this data base. It has divided the vegetable oil industry into two distinct sectors of crude and refined vegetable oil. The original GTAP data base represents all food and feed industries under one sector, called other foods. THTBB also has split this aggregated sector into two distinct feed and food industries. We revisit these splits to better represent the stream of crude and refined vegetable oils and their by-products among the food, feed, biodiesel, and livestock industries. In this revision we used a very detailed input–output table of the U.S. economy of 1997 to define technologies of production and components of demands for the new sectors.[6] Then we introduced these production

[5] The composite of processed livestock carries a small share in total costs of feed across all types of livestock industries.

[6] This was the most updated input-output table with very detailed economic activities available when we were introducing the new sectors into the GTAP data base. The Bureau of Economic Analysis of the U.S. Departments of Commerce has published a new detailed table for 2002. The structures of food and feed sectors of this table are not very different from their corresponding of 1997.

technologies and sale distributions into the *Split.Com* software[7] to split the original food industry of the GTAP data base into two new industries of food and feed. In the split processes, we iteratively made changes in the costs and sales distributions and compared the results of the split with independent global data sets on oilseed, vegetable oil, and their meals production and consumption (FAPRI, 2002) to make the final outcomes of the split processes consistent with the actual observations.

THTBB has aggregated the world economy into 28 sectors, 30 commodities, and 18 regions. In this article, we expand the sets of industries, commodities, and regions into 31, 33, and 19, respectively. In addition, we redefined the geographic/political aggregation scheme of the regions according to their natural land cover type. For example, we combined Malaysia and Indonesia with the same tropical forestland cover into one region. Our data base aggregates commodities into: six groups of crops, one forestry product, six groups of livestock and processed livestock products, three groups of food and beverages, two vegetable oil products, three animal feed commodities, three types of biofuels, five energy commodities, and four groups of other goods and services. Appendix Tables A1 and A2 show the lists of sectors, commodities, regions and their components.

5. Modeling biofuel mandates

To model biofuel mandates we did two distinct sets of baseline and *ex ante* simulations. The baseline simulations are used to incorporate the expansion in the global biofuel industry during the time period of 2001–2006 into the GTAP data base and calibrate parameters of the model according to historical observations from this time period. To construct the baseline following Hertel et al. (2010) we first defined an experiment which only shocks the key economic variables such as crude oil price, global biofuel subsidies, and biofuel shares in fuel markets that shape the expansion of the global biofuel economy in the time period of 2001–2006. This approach reduces the need for information for constructing a comprehensive baseline and isolates impacts of biofuel production from other changes in the world economy for the time period of 2001–2006. Then, we did several simulations to calibrate the elasticities of substitution applied in the demands of the livestock industries for feed according to the historical changes in the prices of corn, oilseeds, oilseed meal in the time period of 2001–2006. In the calibration process we also matched the historical changes in the feed composite of the livestock industries of the United States and EU with their corresponding figures obtained from the baseline simulations.

To model biofuel mandates we shocked the updated 2006 global economy obtained from the historical simulation with U.S. and EU biofuels mandates expected to be in place for 2015. In particular, this article examines the global impacts of the U.S. Energy Independence and Security Act of 2007 and the European Union mandates for promoting biofuel production. Hertel et al. (2010) have translated these mandates into the shares of biofuels in fuel consumptions of these two regions in 2015. According to their calculations the shares of ethanol and biodiesel in transport liquid fuel of the United States will be 4.53% and 0.56% in 2015. The corresponding figures for the EU are about 1.0% and 5.25%.

We undertake four different *ex ante* experiments in this article. These experiments follow the same biofuel targets for 2015, but they isolate different economic linkages in the overview provided in Fig. 4. The first forward looking experiment represents the *full effect experiment*, which features all of these linkages, including multinational mandate programs to boost production and consumption of biofuels in several regions; there is a competition in the land market between crop, livestock, and biofuel industries; biofuel by-products are included into the framework; and final demands (both domestic consumption and trade) respond to biofuel production.

In addition to this *full effect experiment*, we develop three sequential *restricted experiments* to isolate the contribution of particular linkages in Fig. 4. The restricted experiments are as follows:

(1) The *first restricted experiment* imposes a constraint on the *full effect experiment* by assuming that biofuel mandates do not affect final demands for food items—food demand is held constant. By considering the difference between this experiment and the full effect experiment, we are able to identify the interactions between the food and biofuel markets.
(2) The *second restricted experiment* introduces another constraint into the picture and assumes that, in addition to the absence of final demand adjustments, the livestock producers do not use biofuel by-products; differencing the second and third experiments highlights the role of biofuel by-products in the changing configuration of global livestock production.
(3) Finally, in the *third restricted experiment* in addition to the first and second constraints we eliminate competition between livestock and biofuel feedstock production industries in the land market. By fixing the price of pastureland such that the supply of land to the livestock sector is perfect elastic, we are able to identify the role of competition in the land market in such analysis.

A full set of these experiments along with the model and the data base used in this article are posted on the GTAP website.[8] Interested readers may obtain the full numerical results of these experiments from this website as well. In presenting the results, we first analyze the *full effect experiment* to investigate the global impacts of the United States and biofuel mandates. Then

[7] This software was developed at the Monash University to split an industry into new sectors given some information on their costs and sales distributions. For more information, see: http://www.monash.edu.au/policy/splitcom.htm

[8] https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3194.

we use the results of the restricted experiments to discuss the key links for the biofuel economy.

6. *Ex ante* analyses

6.1. Global implications of the U.S. and EU biofuel mandates: Full effect experiment

We now analyze the global implications of the U.S. and EU biofuel mandates using the results obtained from the *full effect* experiment. Here, we analyze impacts on production, consumption, and trade of those commodities that are keys in understanding the consequences of mandates for the livestock industry (Appendix Table C1–Table C5 provide greater detail on these impacts). We also provide some simulation results which measure impacts of the mandates on the cost and production structures of livestock industries. The global land use implications of mandates will be discussed as well. In some illustrations we divide the whole world into four regions: the United States, EU, Brazil, and all other (nonbiofuel producing) regions to summarize the results.

6.1.1. Impacts on outputs

Biofuel mandates are expected to sharply increase production of coarse grains in the United States (by $2.5 billion, or about 11.2%), sugarcane in Brazil (by $0.5 billion or 13.6%), and oilseeds in EU (by $2.4 billion, or 32.6%), all at constant prices and measured relative to our baseline 2006 biofuel benchmark. On the other hand, the mandates significantly depress production of some other crops in these biofuel producing countries as cropland is diverted to produce biofuel feedstocks. For example, mandates are estimated to reduce production of other agricultural commodities in the United States (by $1.8 billion, or about –2.8%), Brazil (by $0.4 billion, or –4%), and EU (by $3.6 billion, –3.2%). The biofuel mandates induce changes in crop production in many nonbiofuel countries as well. For example, the U.S. and EU mandates are expected to increase production of oilseeds in the nonbiofuel regions by $3 billion (or 6.3%). In general, mandates serve to boost production of agricultural commodities in nonbiofuel regions by about $7.3 billion (Appendix Table C1).

While mandates boost production of crop commodities globally, they serve to reduce the global production of livestock and processed livestock products. The global volume of primary livestock and processing livestock industries is expected to fall by about $3.7 billion. About 61.7% of this reduction will take place within nonbiofuel producing regions. The United States is estimated to experience a minor reduction ($0.9 billion) in its livestock and processed livestock products, while the EU experiences a negligible increase. In general, the livestock industries of the United States and EU do not suffer significantly from biofuel mandates, because they make use of the biofuel by-products, which greatly mitigate the cost consequences of higher crop prices. In contrast, the livestock industries of other regions have limited access to biofuel by-products, in particular to DDGS, and therefore the U.S. and EU biofuel mandates play a stronger role in curbing their outputs. Fig. 6 shows impacts of biofuel mandates on the outputs (in $U.S. millions at constant prices) of dairy farms, meat ruminant, and nonruminant activities by region. It may be seen that the outputs of these industries fall in all regions except for the EU. The outputs of the meat ruminant and nonruminant activities of the EU slightly grow due to biofuel mandates. In this region biodiesel mandates strongly increase supplies of cheaper oilseed meals and their uses in the feed rations, offsetting the uses of other feed crops. At the global level the nonruminant sector will experience the greatest output volume reduction among all livestock sectors. This sector is least able to take advantage of the increased availability of DDGS.

Biofuel mandates are also expected to increase production of oilseed meals in the EU by $2.9 billion or 76.6%, and of DDGS in United States by $2.1 or 181.8%. Later on in this article,

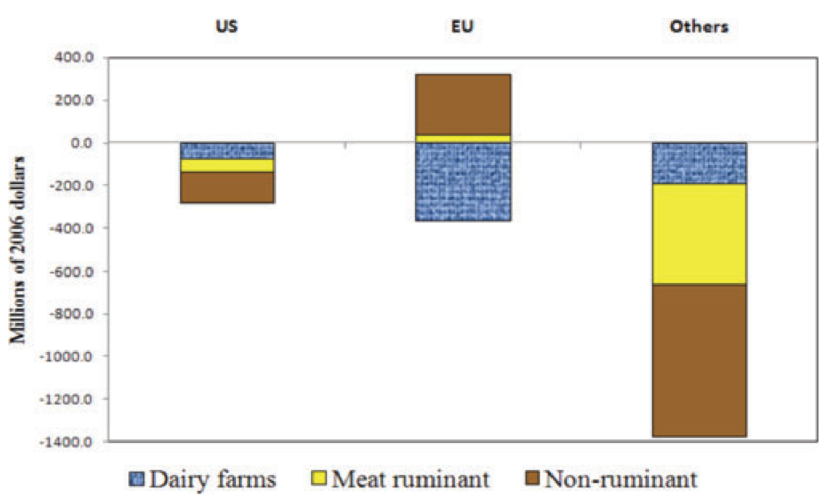


Fig. 6. Changes in global livestock outputs due to the EU and U.S. 2015 biofuel mandates.

we will show that these sharp increases in by-products induce major changes in feed rations.

6.1.2. Impacts on livestock input prices

The biofuel mandates significantly increase the price of cropland all across the world, and in particular in the United States, EU, and Brazil. This raises the price of pastureland everywhere, except for East Asia. For example, the results of the full effect experiment indicate that the biofuel mandates increase the price of U.S. and EU pasturelands by 17% and 29%. At the same time the livestock producers must pay higher prices for crops. For example, the prices of coarse grains and oilseeds go up by 13% and 19% in the United States and EU, respectively, because of the 2015 mandates (Appendix Table C2). On the other hand, massive biofuel production drastically increases outputs of all types of processed feeds (including DDGS and meals). This reduces the prices of these feed materials either in absolute terms or relative to the crop prices. For example, the price of oilseed meal in the United States and EU and some other regions significantly falls[9] (Appendix Table C2). While in the United States the price of DDGS increases less than the price of coarse grain, 4% for DDGS versus 12.6% for coarse grains. For this reason, the livestock industries of the United States and EU are able largely to escape the adverse price impacts of the biofuel mandates. However, the livestock industries of other regions, which have limited or no access to low cost by-products will suffer from biofuel mandates. Indeed, biofuel mandates put the livestock industries of the United States and EU in a better relative position in the world market.

6.1.3. Impacts on household demands

Here we consider the impacts of biofuel mandates on household demands for major food items such as crops, livestock, processed livestock, edible oil, beverage–tobacco–sugar, processed rice, and other food products. In general, biofuel mandates are expected to reduce global quantities demanded by households for these items, and this is indeed the case (Appendix Table C3). The overall reductions in food demands in the United States and the EU are about $2.2 and $3.7 billion, respectively, when measured at 2006 constant prices. The overall reduction in the world demand for food products is about $10.3 billion of which $2.4 billion (or 23.3%) is related to reduction in demands for livestock and processed livestock products. The global reductions in household demand for crops, edible oil, and other food items (including tobacco, beverage, sugar, processed rice, and other processed food) are about $2.35 billion, $0.8 billion, and $4.7 billion (see Appendix Table C3).

While the magnitudes of reductions in demands for food items mentioned above are relatively high, in particular in the United States and EU, their percentage changes are usually small and less than 1% across the world, except for the edible oil which experiences the highest rate of reduction in household demand, ranging from –0.1% (in China) to –7.2% (in the United States). These results indicate that unlike the general perception, the independent impacts of biofuel production on food demands are not large, in particular for the nonbiofuel producers. However, one should take into account that even small reductions in the demand for food items in some regions such as North Africa and Central and South America may seriously worsen malnutrition problems.

6.1.4. Impacts on trade

The biofuel mandates alter global trade patterns for crops, crude and refined vegetable oils, livestock, and processed livestock products. We analyze changes in the trade balances of these commodities for the United States, EU, Brazil, and nonbiofuel regions. In general, while mandates serve to reduce trade balances of the United States, EU, and Brazil by $1,133, $572, and $108 million, they improve the combined trade balances of other regions by $1,813 million (Appendix Table C4).

EU members need to import significant amounts of these commodities to satisfy their biofuel goals. The biofuel mandates increase the EU agricultural trade deficits by about $6,606 million. On the other hand, biofuel mandates put the EU livestock and processed livestock industries in a better position compared to other regions. The mandates increase the EU trade balances of livestock and processed livestock products by $207 and $559 million, respectively. The mandates also improve the EU trade balances on conventional fuels (less imports of crude oil and its products) and exports of industrial commodities. These items are included in other goods and services. As shown in Appendix Table C4, mandates increase the net exports of these commodities by $5,235 million. The United States and EU biofuel mandates improve the United States trade balances for livestock (by $18 million), processed livestock (by $90 million), and animal feed products including DDGS (by $379 million) and other processed feed (by $170 million). The nonbiofuel producing regions are expected to see an improvement in their trade balance for agricultural products (by $5,518 million) and food products (by $929 million), while imports rise faster than exports in all other commodities and services (Appendix Table C4). In particular, the nonbiofuels regions which export fossil fuels will suffer from reductions in their fossil fuel trade balances. Nonbiofuel regions are expected to observe a reduction in their trade balance of other goods and services by $3,592 million, mainly due to reduction in exports of crude oil and its products.

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[9] The sharp reduction in the price of oilseed meal is due to the sharp increase in vegetable oil production all across the world to support the U.S. and EU biodiesel mandates. These mandates will increase harvested oilseed areas by 1.1, 4.2, and 9.4 million hectares in the U.S., EU, and other regions, respectively. While we project a sharp reduction in the price of oilseed meal due to mandates, one should not expect to observe such a reduction in the price of oilseed meals in real world in the future. As noted earlier in this paper our forward looking simulations isolate impacts of biofuels mandates from other key economic and demographic factors, which could shape the future of the world economy. Income and population growth, for example, could offset this price drop, but those factors are not included in this analysis. We emphasize that in this paper we seek to estimate the independent effect of the mandates, and not to predict future changes in economic variables.

6.1.5. Impacts on composite of animal feeds

The numerical results of the full effect experiment indicate that mandates mainly alter the composition of animal feeds in the United States and EU with marginal changes in other regions. These numerical results also show that the processed feed industry also changes the composition of its inputs to use more by-products rather than crops. In what follows we illustrate the overall changes in the composition of animal feeds (including changes in the composition of the processed feedstuffs) used by the livestock industries of the United States and EU. We calculate changes in cost shares at constant prices and therefore they only reflect changes in feed intensity.

The mandates will significantly reduce the cost share of coarse grains in feed rations in the United States and EU and raise shares of DDGS and oilseed meals across all livestock industries (see panels A, B, and C of Fig. 7). The ruminant meats industry benefits more from the expansion of DDGS than other livestock activities. The cost share of DDGS in the feed composition of ruminant meats in the United States is projected to increase from 4.8% to 12.5% due to mandates (Fig. 7 panel B). The corresponding numbers for the dairy farms industry are 3.8% and 10.3% (Fig. 7 panel A) and for the nonruminant industry are 1% and 3% (Fig. 7 panel C). This ability to absorb biofuel by-products cushions the decline in ruminant and dairy farm outputs in the United States, which fall by less than half of the amount of nonruminants ($73 million and $63 million vs. $145 million) (Appendix Table C2).

One can see a similar pattern of by-product use in the EU. In this region the share of DDGS in the feed composite of ruminant meats industry increases from 1.4% to 7.4% (Fig. 7 panel B) due to mandates. The corresponding numbers for the dairy sector are 1.1% and 4.7% (Fig. 7 panel A) and for the nonruminant sector are 0.3% and 0.9% in the EU region (Fig. 7 panel C). Increased production of biodiesel results in a reduction in oilseed meals prices and causes a strong increase in the feed intensity of this input in the EU across all the livestock industries, including nonruminants. On the other hand, mandates reduce the use of other grains (mainly wheat) used in the EU livestock industry.

6.1.6. Land cover implications

Finally, we investigate the consequences of biofuel mandates for land cover across the world. The United States and EU biofuel mandates are jointly expected to increase the global cropland area by 11.8 million hectares (for details see Appendix Table C5). The shares of United States, EU, Brazil, and nonbiofuel regions in this figure are about 10.0%, 20.7%, 12.3%, and 57%, respectively. The shares of forest and pastureland in total land conversion due to the biofuel mandates are about 23% and 77%. The share of forest in the EU land conversion is high (about 73%). This means that biofuel mandates will lead to significant deforestation in EU. The shares of forest in the land conversion of United States, Brazil, and other regions are about 36%, 27%, and 1%. This suggests that nonbiofuel regions will mainly convert their pastureland to support crop production induced by the United States and EU biofuel mandates.

The biofuel mandates not only cause conversion of forest and pastureland to crop production, they also alter allocation of cropland among crop industries. These mandates are expected to increase areas under production of oilseed, coarse grains, and sugar crops by about 14.8, 1.8, and 0.5 million hectares at the global scale. On the other hand, mandates reduce areas under production of paddy rice, wheat, and other agricultural items by about 1.4, 0.4, and 3.4 million hectares. For the geographical distribution of these changes see Appendix Table C5. We will also provide more land use analyses when we discuss our restricted experiments.

6.2. Important links and interactions in measuring biofuel impacts: Restricted experiments

In this section we compare the results of the *full effect experiment*, discussed earlier, with their corresponding results obtained from the *restricted experiments* to better understand the nature of competition between food and fuel, the availability of biofuel by-products, and competition between the livestock and crop industries in the market for land could alter the results of the full effect experiment. Here we only compare some key variables across the full effect and the restricted experiments. In particular, we examine the impacts of mandates on the outputs, prices, and trade balances of three major crops (coarse grains, oilseeds, and other crops) and livestock products of the U.S. and EU economies. We also study changes in the areas under the production of these crops and changes in pastureland areas in these two regions. Appendix Tables D1 and D2 show detailed results we describe below.

6.2.1. First restricted experiment: Fixed food consumption

In this experiment we assume that demands for food items are fixed in the face of biofuel mandates. Compared to the full effect experiment, we observe larger changes in the prices for all crops and livestock products (compare the percentage changes in the prices shown in the first two panels of Table D1 of Appendix D). For example, with the fixed demands for food items the prices of coarse grains and oilseeds in the U.S. increase by 13.9% and 12.7% compared with 12.6% and 11.2% in the full effect experiment. In the case of fixed food demand, the U.S. and EU economies must produce more crops and livestock products, in general. For example, compare the percentage changes in the production of other crops in the United States under the full effect experiments (–2.8%) and the fixed food case (–1.8%). These figures indicate that when the food demand is fixed the U.S. economy needs to produce more crops. One can observe the same pattern in the EU and other regions as well (see the first two panels of Table D1 of Appendix D). This means that when demand for food is fixed the world economy needs to convert more forest and pastureland to crop production to support biofuel production. In this case about 14 million hectares

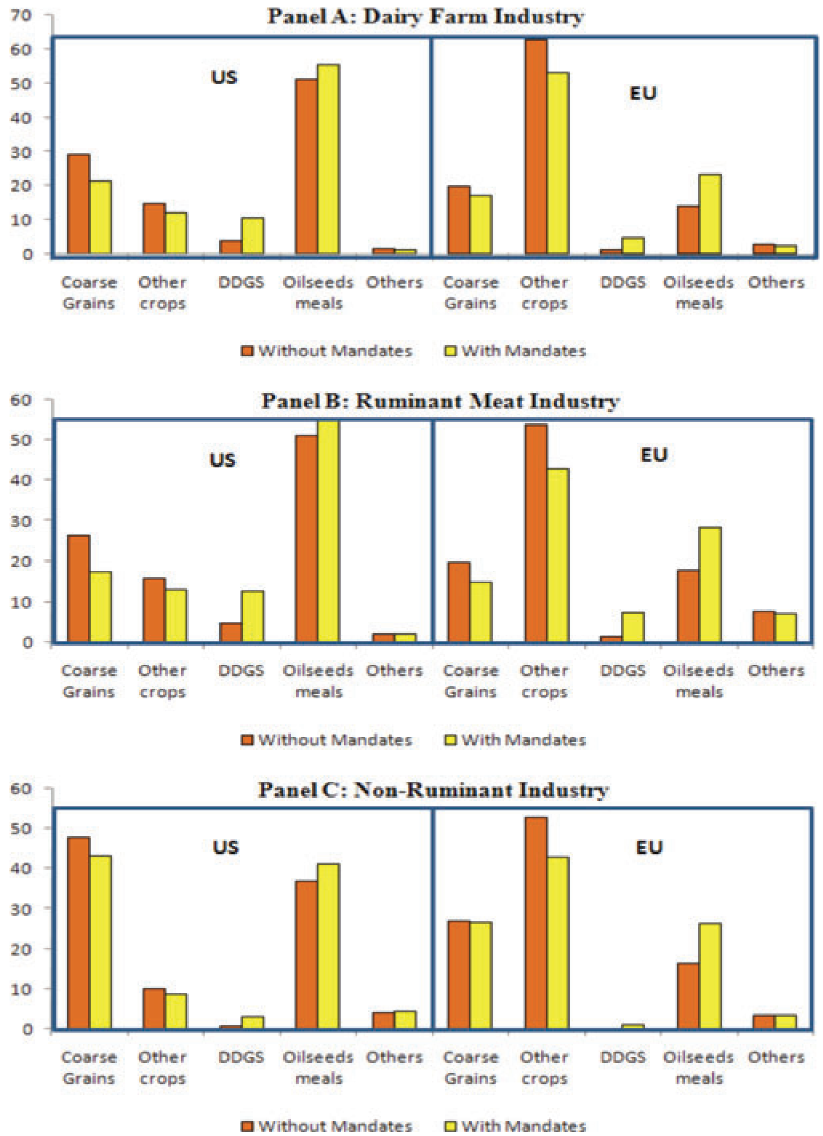

Fig. 7. Shares of coarse grains, DDGs, and oilseeds meals in total costs of animal feed rations without and with the EU and U.S. 2015 biofuel mandates (figures represent cost shares calculated at constant 2006 prices).

of new croplands (compared with 11.8 million hectares of the full effect) are needed to support the United States and biofuel mandates, see the first two panels of Table D2 of Appendix D for more details. In general, when demands for food items are constant, exports rise more than imports in the United States and EU and the trade balances in these two regions rise by \$593.8 million and \$414.6 million respectively, when compared with the full effect experiment. See the first two panels of Appendix Table C1 for the impacts of this assumption on the trade balances of the major crops and livestock commodities of the United States and EU.

6.2.2. Second restricted experiment: Fixed food consumption and no by-products

In addition to the first restriction, we now assume that the livestock producers do not use generated by-products due to the United States and EU biofuel mandates. In this case, prices of all crops and livestock commodities increase much more than under the full effect experiment (compare the first and third panels of Appendix Table C1). In this case the United States and EU along with other regions must produce more coarse grains and oilseeds to meet the biofuel mandates. For example, the United States now expands its coarse grains outputs by 15.4% (vs. 11.2% of the full effect) and the EU needs to boost its oilseed outputs by 39.9% (vs. 32.6%) to meet the biofuel mandates. Hence, more land is needed. Indeed, when biofuel by-products cannot be used in livestock industry and the demand for food is fixed, the world economy needs to convert 19.8 million hectares of forest and pasture land to new cropland to support biofuel mandates. The difference between the global land conversions under the first and second restricted experiment is about 5.8 million hectares. This shows the size of saving in land conversion (about 49% of the land conversion in the full experiment), when we include biofuel by-products and final demand responsiveness into our modeling framework (for region distribution see the third panel of Appendix Table C2).

6.3.3. Third restricted experiment: Fixed food consumption, no by-products, no land constraint

In addition to the first two constraints, here we also eliminate the competition between livestock and other activities by confronting the livestock industry with a perfectly elastic supply of land. This means that the biofuel and livestock industries do not compete for land when we shock production and consumption of biofuels. In this case prices of crops go up, but significantly less than what we observed in the second restricted experiment. When the price of land is fixed for the livestock producers, they bring more lands into their production process and move away from expensive crops. This substitution reduces the prices of livestock products, but does not limit their outputs (see the last panel of Appendix Table C1). When we assume no competition for land, biofuel mandates cause a major deformation. In this case about 16.9 million hectares of additional croplands are needed to meet the biofuel mandates, of which 93.8% is forest. This has a major implication for the land use emissions due to biofuel production, since converting forestland to cropland causes much more emissions than pastureland per unit of land.

In summary, these three restricted experiments indicate that competition between food and fuel, availability of biofuel by-products, and competition between the livestock and crop industries are key elements in analyzing the economic and environmental impacts of biofuel production. Accordingly, any partial and general equilibrium analyses of biofuel production that ignore these factors will be misleading.

7. Conclusion

In this article, we offer a general equilibrium analysis of the impacts of United States and EU biofuel mandates for the global livestock sector. Our experiments boost biofuel production in the United States and EU from 2006 levels to mandated 2015 levels. We developed several experiments to decompose links between biofuel, livestock, crop, food, and feed industries and investigate competition among them for land. We show that mandates will encourage crop production in both biofuel and non biofuel producing regions, while reducing livestock and processed livestock production in most regions of the world. The nonruminant industry curtails its production more than other livestock industries because it is less able to take advantage of biofuel by-products.

An important finding of this study pertains to the relative impact of United States and EU biofuel programs on the livestock sectors in those regions, versus the rest of the world. Due to the relatively undeveloped international trade in ethanol by-product (DDGS), we estimate that the United States–EU mandates will result in larger absolute reductions in livestock production overseas, as opposed to in the biofuel producing regions themselves. This is due to the relatively greater transmission of grains prices into the overseas markets, as compared to the transmission of by-product prices, in particular for DDGS price. Of course, this result could change in the future with greater international integration of by-product markets.

The numerical results suggest that the biofuel mandates reduce food production in most regions while they increase crude vegetable oil in almost all regions. Implementing biofuel mandates in the United States and EU will increase croplands within the biofuel and nonbiofuel producer regions. A large portion of this increase will be obtained from reduced grazing lands. The biofuel producing regions are expected to reduce their coarse grains exports and raise imports of oilseeds and vegetable oils. While all livestock industries use more biofuel by-products in their animal feed rations, the dairy and other ruminant industry benefit most from the expansion of DDGS. We conclude that, while biofuel mandates have important consequences for the livestock industry, they do not harshly curtail these industries. This is largely due to the important role of by-products in substituting for higher priced feedstuffs.

Acknowledgements

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Table A1
List of industries and commodities in the new model

Industry	Commodity	Description	Commodities included
Paddy_Rice	Paddy_Rice	Paddy rice	Pdr
Wheat	Wheat	Wheat	Wht
CrGrains	CrGrains	Cereal grains	Gro
Oilseeds	Oilseeds	Oil seeds	Osd
OthAgri	OthAgri	Other agriculture goods	ocr, pfb, v_f
Sugarcane	Sugarcane	Sugar cane and sugar beet	c-b
DairyFarms	DairyFarms	Dairy products	Rmk
Ruminant	Ruminant	Cattle & ruminant meat production and	Ctl, wol
NonRum	NonRum	Nonruminant meat production	oapl
ProcDairy	ProcDairy	Processed dairy products	Mil
ProcRum	ProcRum	Processed ruminant meat production	Cmt
ProcNonRum	ProcNonRum	Processed nonruminant meat production	Omt
Forestry	Forestry	Forestry	Frs
Cveg_Oil	Cveg_Oil	Crude vegetable oil	A portion of vol
	VOBP	Oil meals	A portion of vol
Rveg_Oil	Rveg_Oil	Refined vegetable oil	A portion of vol
Proc_Rice	Proc_Rice	Processed rice	Pcr
Bev_Sug	Bev_Sug	Beverages, tobacco, and sugar	b_t, sgr
Proc_Food	Proc_Food	Processed food products	A portion of ofd
Proc_Feed	Proc_Feed	Processed animal feed products	A portion of ofd
OthPrimSect	OthPrimSect	Other primary products	fsh, omn
Coal	Coal	Coal	Coa
Oil	Oil	Crude oil	Oil
Gas	Gas	Natural gas	gas, gdt
Oil_Pcts	Oil_Pcts	Petroleum and coal products	p-c
Electricity	Electricity	Electricity	Ely
En_Int_Ind	En_Int_Ind	Energy intensive industries	crpn, i_s, nfm, fmp
Oth_Ind_Se	Oth_Ind_Se	Other industry and services	atp, cmn, cns, ele, isr, lea, lum, mvh, nmm, obs, ofi, ome, omf, otn, otp, ppp, ros, tex, trd, wap, wtp
NTrdServices	BTrdServices	Services generating non-CO_2 emissions	wtr, osg, dwe
EthanolC	Ethanol1	Ethanol produced from grains	
	DDGS	Dried distillers grains with solubles	
Ethanol2	Ethanol2	Ethanol produced from sugarcane	
Biodiesel	Biodiesel	Biodiesel produced from vegetable oil	

Table A2
Regions and their members

Region	Description	Countries included
USA	United States	usa
EU27	European Union 27	aut, bel, bgr, cyp, cze, deu, dnk, esp, est, fin, fra, gbr, grc, hun, irl, ita, ltu, lux, lva, mlt, nld, pol, prt, rom, svk, svn, swe
Brazil	Brazil	bra
CAN	Canada	can
Japan	Japan	jpn
CHIHKG	China and Hong Kong	chn, hkg
India	India	Ind
C_C_Amer	Central and Caribbean Americas	mex, xna, xca, xfa, xcb
S_o_Amer	South and other Americas	col, per, ven, xap, arg, chl, ury, xsm
E_Asia	East Asia	kor, twn, xea
Mala_Indo	Malaysia and Indonesia	ind, mys
R_SE_Asia	Rest of South East Asia	phl, sgp, tha, vnm, xse
R_S_Asia	Rest of South Asia	bgd, lka, xsa
Russia	Russia	rus
Oth_CEE_CIS	Other East Europe and Rest of Former Soviet Union	xer, alb, hrv, xsu, tur
R_Europe	Rest of European Countries	che, xef
MEAS_Nafr	Middle Eastern and North Africa	xme,mar, tun, xnf
S_S_AFR	Sub-Saharan Africa	bwa, zaf, xsc, mwi, moz, tza, zmb, zwe, xsd, mdg, uga, xss
Oceania	Oceania countries	aus, nzl, xoc

Table B1
Cost shares of major feed items in the U.S. livestock industries in 2001 and 2006*

	Description		Dairy	Meat ruminant	Nonruminant	Overall livestock
US	Coarse grains	2001	67.3	68.1	82.9	76.9
	Other crops		6.4	10.3	2.9	5.0
	DDGS		6.1	6.8	1.1	3.2
	Oilseed meals		20.2	14.8	13.1	14.9
	Coarse grains	2006	58.3	53.5	81.5	71.5
	Other crops		6.0	9.6	2.8	4.7
	DDGS		14.7	21.2	2.2	8.3
	Oilseed meals		21.0	15.7	13.6	15.5
EU	Coarse grains	2001	24.3	28.7	43.5	35.9
	Other crops		69.6	57.8	48.3	55.9
	DDGS		0.7	0.9	0.3	0.5
	Oilseed meals		5.3	12.7	7.9	7.7
	Coarse grains	2006	23.0	26.2	43.2	35.0
	Other crops		67.8	54.8	46.8	54.1
	DDGS		2.3	3.6	0.7	1.6
	Oilseed meals		7.0	15.3	9.3	9.4

Table C1
Changes in the outputs of agricultural and livestock industries due to the EU and U.S. 2015 biofuel mandates: $ million at constant 2006 prices

Description	USA	UE27	Brazil	Others	World
Volume changes					
Paddy rice	−36.9	−4.8	−20.7	−63.8	−127.5
Wheat	−243.2	31.2	−10.5	809.7	581.3
Coarse grains	2500.7	−493.7	−45.2	459.2	2487.9
Oilseeds	825.5	2441.0	824.8	2957.4	7126.1
Sugar crops	−7.6	13.0	459.3	18.3	498.1
Other crops	−1812.5	−3639.8	−411.7	3104.8	−2843.8
Total crops	1226.0	−1653.0	796.0	7327.2	7895.1
Dairy farms	−72.7	−365.6	4.0	−192.9	−626.8
Meat ruminant	−62.9	40.0	−109.8	−360.2	−494.6
Nonruminant	−144.8	284.4	−102.0	−611.4	−578.7
Processed dairy	−217.3	−421.5	−22.8	−211.9	−873.6
Processed meat ruminant	−136.4	69.4	−177.7	−398.5	−645.1
Processed nonruminant	−220.8	481.5	−218.2	−493.8	−455.7
Total livestock	−854.9	88.2	−626.6	−2268.4	−3676.0
DDGS	2107.2	649.8	0.0	1.5	2740.3
Oilseed meals	662.5	2936.7	−29.5	894.1	3473.1
Percentage changes:					
Paddy rice	−4.2	−0.5	−1.8	−0.1	−0.1
Wheat	−3.8	0.2	−4.4	1.1	0.6
Coarse grains	11.2	−2.7	−1.9	0.7	2.4
Oilseeds	6.4	32.6	13.0	6.3	9.7
Sugar crops	−0.3	0.3	13.6	0.1	1.4
Other crops	−2.8	−3.2	−4.0	0.6	−0.4
Total crops	1.1	−1.0	3.4	2.1	0.6
Dairy farms	−0.3	−0.8	0.1	−0.2	−0.4
Meat ruminant	−0.2	0.1	−2.0	−0.4	−0.3
Nonruminant	−0.4	0.5	−1.9	−0.3	−0.2
Processed dairy	−0.3	−0.4	−0.3	−0.2	−0.3
Processed meat ruminant	−0.2	0.1	−1.9	−0.4	−0.3
Processed nonruminant	−0.3	0.4	−4.7	−0.4	−0.1
Total livestock	−0.3	0.0	−1.8	−1.0	−0.4
DDGS	181.8	413.8	0.0	6.4	204.7
Oilseed meals	10.5	76.6	−1.4	15.9	19.5

Table C2
Percentage changes in the prices of major feedstuffs and pastureland due to the EU and U.S. 2015 biofuel mandates (base year is 2006)

Regions	Coarse grains	Oilseeds	Processed feed	Oilseed Meal	DDGS[a]	Pastureland	Cropland[b]
USA	12.6	11.2	−3.5	−23.4	4.1	16.7	46.5
EU27	6.5	19.1	−4.8	−75.3	−4.7	28.8	81.0
Brazil	6.4	10.8	5.7	7.5	NP	21.9	72.1
CAN	3.4	7.0	0.0	−9.4	NP	11.0	49.1
Japan	2.2	2.2	1.6	−2.1	NP	4.2	12.6
CHIHKG	1.5	3.8	1.9	7.6	NP	3.1	7.8
INDIA	2.1	3.9	2.1	1.0	NP	2.4	7.1
C_C_Amer	3.8	7.2	3.6	0.0	NP	6.0	16.1
S_o_Amer	4.4	9.8	3.2	4.7	NP	8.2	29.5
E_Asia	2.1	4.2	3.6	4.9	NP	−0.7	5.0
Mala_Indo	3.4	18.6	1.1	−21.9	NP	4.1	16.9
R_SE_Asia	2.4	6.4	0.1	−24.2	NP	3.0	6.4
R_S_Asia	1.6	2.9	1.9	2.5	NP	2.2	5.8
Russia	2.1	8.3	1.1	3.9	NP	4.8	12.2
Oth_CEE_CIS	1.3	3.9	1.2	1.9	NP	9.9	24.6
Oth_Europe	3.3	7.9	0.6	−5.2	NP	7.0	20.2
MEAS_NAfr	2.2	4.7	3.1	1.9	NP	9.1	30.1
S_S_AFR	2.3	6.2	−1.0	−33.2	NP	9.1	29.6
Oceania	4.6	8.2	1.2	−4.7	NP	7.5	26.3

[a]Regions with NP either do not producer DDGS or produce only negligible amounts.
[b]Weighted average of changes in cropland prices across crop industries.

Table C3
Changes in the household demands for food product items due to the EU and U.S. 2015 biofuel mandates (base year is 2006–volumes are in $US million at constant prices)

Regions	Crops	Livestock	Processed livestock	Edible vegetable oil	Tobacco, beverage, and sugar	Processed rice	Other processed food
Volume changes:							
USA	−199.2	−60.8	−421.8	−142.7	−484.5	−2.2	−891.6
EU27	−681.3	−51.8	−592.7	−484.8	−587.3	−6.8	−963.7
Brazil	−32.5	−6.1	−25.8	−18.5	−28.3	−4.3	−22.7
CAN	−18.0	−3.0	−40.4	−17.6	−16.6	−0.1	−33.7
Japan	−35.8	−18.8	−83.4	−18.9	−86.4	−17.3	−214.2
CHIHKG	−156.6	−226.7	−38.3	−2.6	−105.8	−36.2	−125.3
India	−113.3	−69.9	−6.4	−16.0	−15.0	−16.1	−11.1
C_C_Amer	−118.2	−13.9	−96.8	−20.1	−72.2	−4.0	−122.2
S_o_Amer	−100.6	−24.1	−63.9	−13.9	−31.0	−4.0	−53.2
E_Asia	−80.2	−17.6	−48.8	−9.4	−19.6	−17.0	−69.2
Mala_Indo	−36.5	−1.8	−4.7	−7.5	−13.7	−18.3	−15.1
R_SE_Asia	−34.4	−2.1	−2.6	−4.0	−10.4	−15.5	−13.0
R_S_Asia	−35.0	−15.1	−5.3	−7.1	−4.7	−11.8	−5.4
Russia	−70.6	−39.1	−53.4	−8.2	−25.5	−1.1	−38.6
Oth_CEE_CIS	−95.0	−25.1	−14.6	−4.8	−18.8	−1.7	−12.8
Oth_Europe	−9.3	−1.7	−24.6	−7.6	−25.0	−0.1	−22.2
MEAS_NAfr	−468.6	−103.6	−143.5	−27.4	−106.5	−21.4	−143.8
S_S_AFR	−48.3	−15.2	−14.9	−11.5	−37.3	−11.1	−33.4
Oceania	−19.7	−1.0	−6.1	−2.7	−10.0	−0.2	−7.2
Percentage changes:							
USA	−0.6	−0.6	−0.3	−7.2	−0.4	−0.2	−0.5
EU27	−0.9	−0.3	−0.3	−1.9	−0.5	−0.3	−0.5
Brazil	−1.0	−0.4	−0.2	−0.8	−0.4	−0.3	−0.1
CAN	−0.7	−0.6	−0.3	−1.8	−0.2	−0.1	−0.2
Japan	−0.1	−0.6	−0.2	−1.3	−0.1	−0.1	−0.2

Continued

Table C3
Continued

Regions	Crops	Livestock	Processed livestock	Edible vegetable oil	Tobacco, beverage, and sugar	Processed rice	Other processed food
CHIHKG	−0.2	−0.4	−0.3	−0.1	−0.3	−0.2	−0.3
India	−0.2	−0.3	−0.1	−0.3	−0.1	−0.1	−0.2
C_C_Amer	−0.9	−0.6	−0.2	−1.2	−0.3	−0.4	−0.3
S_o_Amer	−0.8	−0.5	−0.2	−0.4	−0.1	−0.3	−0.2
E_Asia	−0.5	−0.5	−0.4	−1.2	−0.1	−0.3	−0.4
Mala_Indo	−0.6	−0.1	−0.1	−0.5	−0.2	−0.3	−0.2
R_SE_Asia	−0.4	−0.1	0.0	−0.4	−0.1	−0.2	−0.1
R_S_Asia	−0.2	−0.3	−0.2	−0.4	−0.1	−0.1	−0.1
Russia	−0.7	−0.5	−0.4	−0.9	−0.4	−0.4	−0.4
Oth_CEE_CIS	−0.5	−0.4	−0.2	−0.4	−0.2	−0.1	−0.2
Oth_Europe	−0.3	−0.5	−0.3	−2.4	−0.3	−0.1	−0.3
MEAS_NAfr	−0.8	−0.7	−0.6	−1.0	−0.6	−0.5	−0.6
S_S_AFR	−0.2	−0.2	−0.2	−0.6	−0.2	−0.2	−0.2
Oceania	−0.5	−0.2	−0.1	−0.4	−0.1	−0.1	−0.1

Table C4
Changes in trade balances due to the EU and U.S. 2015 biofuel mandates (base year is 2006–figures are in $U.S. million)

Description	USA	EU27	Brazil	Others	World*
Crops and other agriculture products	−235.3	−6606.0	1127.7	5517.8	−195.7
Livestock	18.4	207.1	−9.8	−206.5	9.1
Processed livestock	90.4	558.6	−310.5	−315.6	22.8
All food products	−625.9	−71.3	−181.2	929.2	50.8
Animal feeds (other than crops)	548.4	104.7	−122.5	−520.5	10.2
Other goods and services	−928.5	5234.5	−611.4	−3591.7	102.8
Total	−1132.6	−572.3	−107.8	1812.8	0.0

*While the change in the global trade balance for all goods and services is zero, this is not the case for individual goods and services since imports are valued at *cif* prices and exports at *fob* prices. The difference is accounted for by changes in global trade and transport services, which are included in the other goods and services category.

Table C5
Changes in land cover due to the EU and U.S. 2015 biofuel mandates: (base year is 2006–figures are in 1,000 ha)

Description	US	EU	Brazil	Others	World
Forest	−426.6	−1800.9	−395.0	−64.0	−2686.5
Pastureland	−755.1	−654.6	−1062.2	−6679.3	−9151.3
Cropland:	1181.8	2455.5	1457.3	6743.3	11837.8
Paddy rice	−76.0	2.0	−82.7	−1254.7	−1411.3
Wheat	−1124.7	70.5	−92.5	708.4	−438.2
Coarse grains	3079.3	−789.7	−281.3	−241.8	1766.4
Oilseeds	1098.8	4226.4	1670.8	7757.0	14752.9
Sugar crops	−28.9	19.7	707.0	−106.0	591.8
Other agriculture	−1766.7	−1073.5	−464.1	−119.6	−3423.8

Table D1
Consequence of the EU and U.S. 2015 biofuel mandates for their crops and livestock industries under alternative experiments (base year is 2006)

Description	Percent change in prices		Percent changes in outputs		Changes in trade balance ($ Million)*	
	USA	EU27	USA	EU27	USA	EU27
Full effect experiment						
Coarse grains	12.6	6.5	11.2	−2.7	99	−72
Oilseeds	11.2	19.1	6.4	32.6	1025	−3448
Other crops	6.0	5.8	−2.8	−3.2	−1335	−2436
Dairy farms	0.6	1.3	−0.3	−0.8	14	32
Ruminant	0.8	0.3	−0.2	0.1	135	195
Nonruminant	0.7	−1.9	−0.4	0.5	−40	539
Total (including trade balances of all commodities)					−1133	−572
Restricted experiment 1, Fixed food consumption						
Coarse grains	13.9	8.4	11.1	−2.9	137	−93
Oilseeds	12.7	22.6	6.5	33.4	1045	−3617
Other crops	7.8	8.2	−1.8	−1.3	−938	−1550
Dairy farms	0.9	2.2	0.0	−0.5	22	−95
Ruminant	1.2	1.1	0.1	0.3	128	172
Nonruminant	0.8	−1.3	−0.1	0.5	−55	397
Total (including trade balances of all commodities)					−539	−158
Restricted experiment 2, Fixed food consumption and fixed use of biofuel by-products						
Coarse grains	23.7	14.9	15.4	−2.3	68	−85
Oilseeds	21.5	36.5	9.0	39.6	994	−5662
Other crops	13.1	14.0	−2.6	−1.1	−1742	−3219
Dairy farms	5.8	6.5	−0.1	−0.1	−4	−262
Ruminant	5.6	6.0	−0.4	−0.4	−250	−142
Nonruminant	5.6	4.7	−0.8	−0.3	−255	−346
Total (including trade balances of all commodities)					−2345	−1901
Restricted experiment 3, Fixed food consumption, fixed use of by-products, and no competition in land market						
Coarse grains	12.3	4.8	15.1	−2.7	−448	−104
Oilseeds	10.7	25.5	9.3	38.9	392	−4911
Other crops	2.8	4.1	−2.6	−1.2	−1213	−1098
Dairy farms	−6.3	−7.2	−0.1	0.4	29	−483
Ruminant	−6.8	−7.6	0.0	0.3	−33	296
Nonruminant	−4.8	−5.5	−0.8	−0.4	−649	−407
Total (including trade balances of all commodities)					746	−3123

*Including livestock and processed livestock industries.

Table D2
Changes in global land cover due to the EU and U.S. 2015 biofuel mandates under alternative experiments (base year is 2006—figures are in 1,000 ha)

Description	US	EU	Brazil	Others	World
Full effect experiment					
Forestry	−426.6	−1, 800.9	−395.0	−64.0	−2, 686.5
Cropland	1,181.8	2,455.5	1,457.3	6,743.3	11,837.8
Pastureland	−755.1	−654.6	−1,062.2	−6,679.3	−9,151.3
Restricted experiment 1, Fixed food consumption					
Forestry	−522.0	−2,122.5	−365.7	−998.3	−4,008.5
Cropland	1,296.7	2,810.0	1,543.9	8,363.3	14,014.0
Pastureland	−774.7	−687.5	−1,178.2	−7,365.1	−10,005.5
Restricted experiment 2, Fixed food consumption and fixed use of biofuel by-products					
Forestry	−671.9	−2,854.6	−581.9	−2,194.5	−6,302.9
Cropland	1,913.5	3,715.3	1,941.3	12,249.7	19,819.8
Pastureland	−1,241.7	−860.7	−1,359.4	−10,055.2	−13,516.9
Restricted experiment 3, Fixed food consumption, fixed use of by-products, and no competition in land market					
Forestry	−2,365.0	−5,039.1	−3,740.7	−4,720.6	−15,865.4
Cropland	1,414.0	2,763.6	1,215.7	11,523.6	16,916.9
Pastureland	951.0	2,275.4	2,525.0	−6,802.8	−1,051.3

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