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Review

Biofuel-Food Market Interactions: A Review of Modeling Approaches and Findings

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Abstract: The interaction between biofuels and food markets remains a policy issue for a number of reasons. There is a continuing need to understand the role of biofuels in the recent spikes in global food prices. Also, there is an ongoing discussion of changes to biofuel policy as a means to cope with severe weather-induced crop losses. Lastly, there are potential interactions between food markets and advanced biofuels, although most of the latter are expected to be produced from non-food feedstocks. This study reviews the existing literature on the food market impacts of biofuels. Findings suggest that initial conclusions attributing most of the spike in global food prices between 2005 and 2008 to biofuels have been revised. Instead, a multitude of factors, in addition to biofuels, converged during the period. Quantitative estimates of the impacts of biofuels on food markets vary significantly due to differences in modeling approaches, geographical scope, and assumptions about a number of crucial factors. In addition, many studies do not adequately account for the effects of macroeconomic changes, adverse weather conditions and direct market interventions during the recent food price spikes when evaluating the role of biofuels.

Keywords: biofuels; food markets; fuels; models; prices; households; economy

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1. Introduction

The global production of biofuels has grown rapidly since 2001. In the United States (US), ethanol production increased from less than 2 billion gallons in 2001 to about 14 billion gallons by 2012 [1]. Global increases in the use of biofuels followed a number of policy initiatives to mitigate rapid increases in global fossil fuel prices, as well as to address the environmental consequences of energy use. In the US, these included the ban on MTBE as a gasoline additive, the 2005 Energy Policy Act (EPAct), and the 2007 Energy Independence and Security Act (EISA) [2]. The ban on MTBE by a number of states in the US due to water contamination from underground tanks, and eventually by the federal government, left ethanol as the main alternative for meeting gasoline oxygenation requirements [3]. The renewable fuel standard in the EISA (known as RFS2) increased the target for biofuels in the earlier EPAct of 2005 from 7.5 billion gallons by 2012 to 36 billion gallons by 2022. The European Union (EU) directive on renewable energy set a target of 10% for biofuels use in its transportation sector by 2020. In addition to Brazil, which pioneered the large scale use of biofuels in transportation, many other countries around the world also have biofuel blending targets [4].

There are concerns that the energy benefits of biofuels may come at the expense of food security. This is because most of the feedstock currently used to produce biofuels, such as corn in the US, sugarcane in Brazil and oilseeds in Europe, are also major globally traded food commodities. Thus, biofuels are seen as potentially diverting land and exports away from food uses to fuel production, net of their by-products. However, even in cases where the biofuel feedstock is not a food crop, such as dedicated energy crops, there are potential indirect links between food and biofuel markets through the competition for land and other resources. These concerns were greatly magnified during the period from 2005 to 2008 when increases in biofuels production coincided with historically high agricultural commodity prices. Specifically, the monthly index of food commodity prices rose by 60% over a two-year period, and led to food protests in many countries [5,6].

A good deal of discussion of the factors contributing to the rapid change in food prices in the latter part of the 2000s has appeared in the literature. Prior to the widespread availability of reliable secondary data on actual production and consumption behavior over the 2005–2008 period a number of authors assessed the relative merit of several alternative factors that could have led to the sharp price increases [7–10]. Most of these initial analyses and commentaries suggested that biofuels were responsible for a large portion of the increase in global food prices. However, subsequent reviews of the empirical data painted a picture of the complex interactions among the determinants of food market dynamics and the implications of food price spikes on consumer welfare. Several factors, in addition to biofuels, converged during the high food price episodes from 2005 to 2008 and from 2010 to 2011 [5,6,11–15]. In general, more recent studies tend to conclude that the impacts of biofuels on food markets are smaller than initially thought [16–22]. In 2012, the US experienced the most severe and extensive drought in several decades [23]. The potential impacts of the drought on corn ethanol production and the potential role of changes in biofuel policy are being examined [24–27].

The current study provides a review of the literature on the food market impacts of biofuels production and use. It outlines the channels and factors that govern biofuel-food market interactions, provides summaries of existing studies that attempt to quantify the roles of these different factors and discusses the sources of differences in the impacts estimated from different studies. The review ends with a concluding section identifying gaps in the literature that need to be addressed for an adequate estimation of the impacts of biofuels on food markets.

2. Biofuels and Food Market Interactions: A Theoretical Outline

An evaluation of the food security implications of biofuels requires the identification and quantification of its impacts on measures of food security. This section provides an overview of the dimensions of food security that may be affected by the production and use of biofuels. It also describes a framework for analyzing the interaction of biofuels with the food market and the larger economy, outlining the theoretical impacts of microeconomic, macroeconomic and other factors on food market outcomes and household welfare.

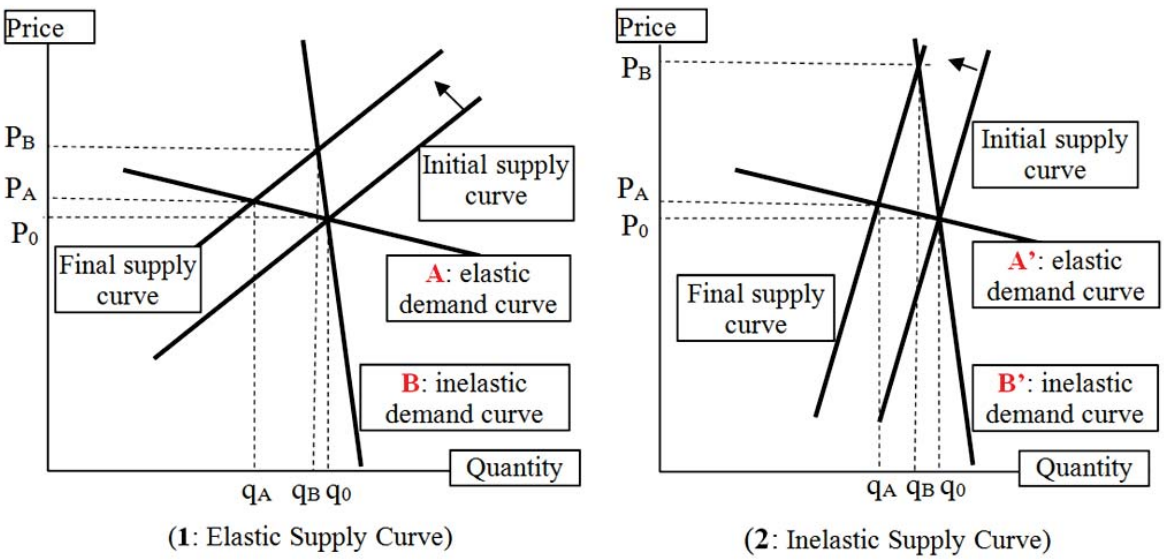
2.1. Dimensions of Food Security

The United Nations (UN) states that "Food security exists when all people, at all times, have physical and economic access to sufficient amounts of safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" [28]. This definition identifies at least five dimensions of food security: adequate quantity, adequate quality, affordable prices, food needs and preferences, and stability of supply over time. Tirado *et al.* [29] discussed four dimensions of food security that are similar to those outlined above: availability, stability, access and utilization. Webb *et al.* [30] noted that food availability, access, and utilization are hierarchical: "food availability is necessary but not sufficient for access, and access is necessary but not sufficient for utilization". Food stability or vulnerability accounts for the risks of disruptions to food availability, access, and utilization from environmental change, conflict and other factors.

Prices are the primary economic signals of ongoing or prospective changes in the desired quantity and quality of food commodities. In addition to changes in price levels, price volatility is a measure of the stability dimension of food security. Wildly fluctuating or sudden price changes suggest rapid changes in the availability or access to food commodities.

Nevertheless, food price levels and volatility are incomplete measures of food security because prices are both outcomes and determinants of food market changes. The "needed, desired and preference" aspects of food security are important. Since it may always be possible to obtain some quantity and quality of food commodities at any given price level, the implications of price changes for food security depend on household needs and preferences. Food prices reflect the balance between demand and supply in the food market. Prices also represent the depletion of household incomes per unit of the desired quantity and quality of food. Thus, without additional information it is difficult to disentangle the influence of supply and demand factors on observed price changes. Different responses to changing food availability or access could be associated with similar food market prices, but have very different food security implications at the household level. Panel (1) of Figure 1 illustrates two opposite cases of household response to supply shocks for a given food commodity. In Case A, the potential effects of the supply loss on prices are almost completely offset by reductions in consumption due to a highly elastic demand curve, leading to a small increase in price. In Case B, household demands are highly inelastic, leading to large price increases. Many food commodities are considered to be essential and therefore highly inelastic in demand. However, loss of access or withdrawal from the market by households may produce seemingly elastic demand curves, with small price implications in the market. In such cases, changes in food prices would not capture the effects of a supply disruption on household welfare. A third possibility is shown in Panel (2) of Figure 1. Case B' combines an inelastic demand curve with an inelastic supply curve. A highly inelastic short-run supply curve could result from the combination of unexpected harvest losses and low crop inventories. As shown in Figure 1, Case B' produces a much larger price effect than Case B, whereas the price effect under Case A' is similar to that of Case A. These hypothetical cases illustrate two points. One is that the market price effects of a given supply shock depend on the demand curves for that commodity, and the other is that price changes alone cannot provide a full measure of the implications of food market changes on household welfare. In addition, the possibility of shifts in the demand curves means that the effects of a supply shock may be more complex than illustrated in Figure 1. Similarly, a significant shift in the demand curve (a demand shock) may generate small or large price effects depending on the slope/shape of the corresponding supply curve. Thus, for practical purposes other measures are needed to complement prices to gauge the household food security and welfare effects of food market changes. Examples of such measures include the percentage of income spent on food, changes in total availability of food crops, proportions of non-food uses of food crops, and proportion of arable land devoted to non-food uses, among others [31].

Figure 1. Illustration of potential price changes in the food market under a supply shock.



2.2. Framework for Analyzing Biofuel-Food Market Interactions

National and global food markets are subject to a host of factors apart from biofuels. The role of non-biofuel drivers would need to be isolated as a first step in clarifying the role of biofuels. Reviews by Trostle, Mueller *et al.*, Trostle *et al.* [5,6,11] and others have identified the following factors as the primary drivers of recent food market changes: (a) Population and income growth; (b) Rising energy prices; (c) Increases in agricultural production costs; (d) Changes in the value of the dollar; (e) Foreign accumulation of exchange reserves; (f) Loss of agricultural land to non-agricultural uses; (g) Financial speculation in commodity markets; (h) Changes in agricultural and trade policies; (i) Declining preference for inventory in favor of just-in-time delivery; (j) Adverse weather conditions; (k) Increasing difficulty to obtain water for agriculture; (l) Potential, but unclear, impacts of climate change.

Most of the above factors are long-term trends that preceded the boom in biofuels, but others are short-term changes. In particular, adverse weather conditions and policy responses in many countries appear to have played a crucial role in recent food price hikes. During the period from 2006 to 2008 adverse weather conditions affected major grain and oil seed producing countries, including the US, Canada, Russia, Ukraine, Australia, Argentina, South Africa, North and Southeast Europe, North West Africa, and Turkey [5]. The multi-year drought in Australia led to the loss of half its wheat production or 2% of the global supply in 2006 and 2007, relative to 2005. The consecutive weather-induced drop in global crop yields in 2006 and 2007 was only the fourth such episode over the last 37 years [5]. In response to the tight global agricultural commodity markets at least 30 countries, including China, India, Argentina, Russia, Malaysia, Indonesia, Ukraine, Vietnam, Serbia, Egypt, Cambodia, Kazakhstan, EU, South Korea, Mongolia, Morocco, Venezuela and Iran among others, imposed different mixes of subsidies, taxes, export restrictions, and export bans in an attempt to protect domestic supplies and ease price spikes [5,6]. An updated review of the empirical data by Trostle *et al.* [11] found that a similar set of long- and short-term factors converged during the period of increases in food commodity prices from June 2010 to February 2011.

Figure 2, adapted for the current review from Rathman *et al.* [32], depicts many of the above drivers of food market changes. Figure 2 is used below to qualitatively trace the potential impacts of biofuels and to describe the complex interactions of factors that drive food market changes.

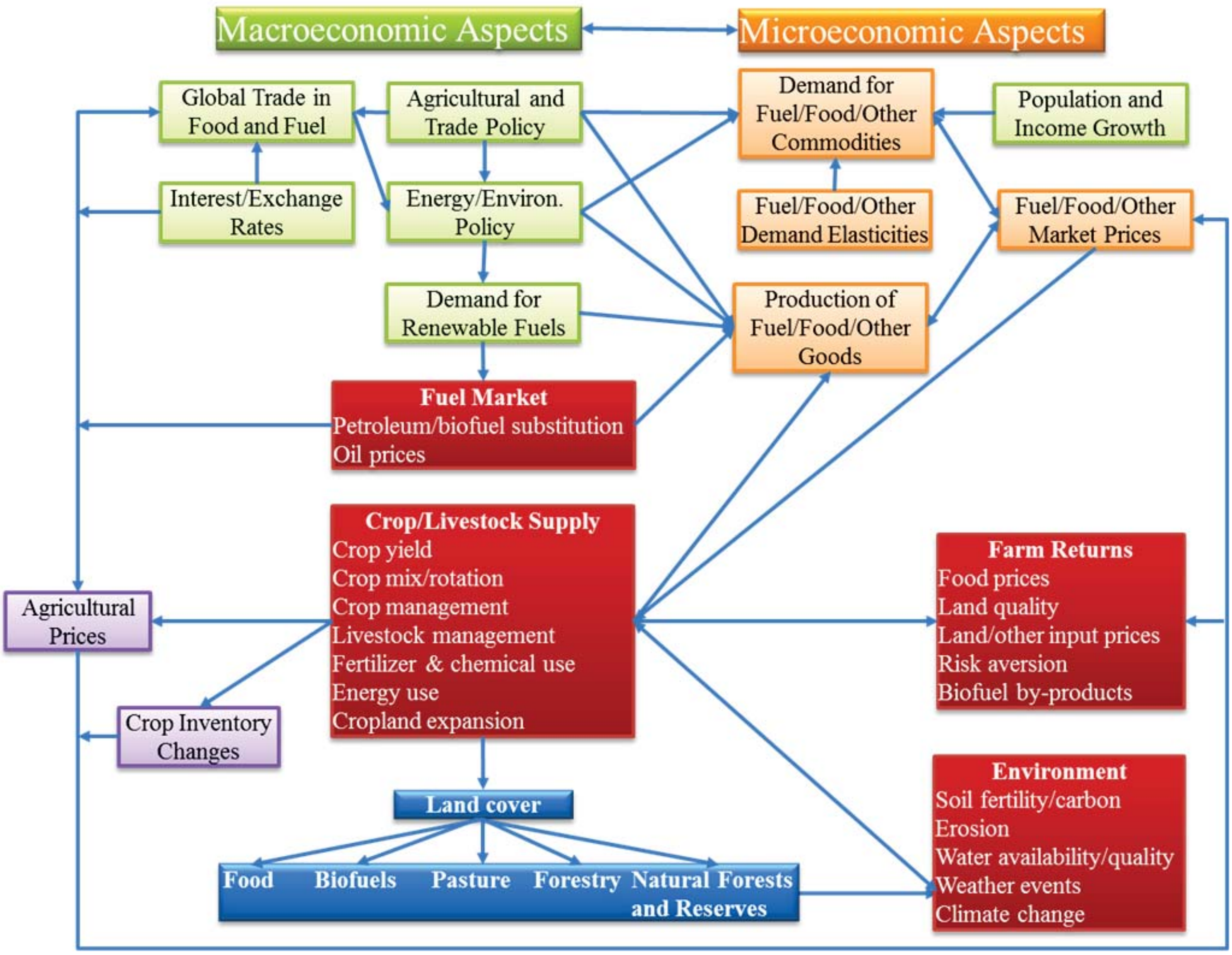
Energy security concerns originating from the global trade in fossil fuels are the primary motivation for biofuel policy. Dependence of the domestic economy on an increasingly tight oil market and potential geopolitical supply disruptions motivate the search for more reliable sources of energy. Consequently, policy makers issue directives for the production and use of renewable fuels, in this case biofuels, combining agricultural, trade, energy and environmental policies. Implementation of the resulting biofuel policies leads to direct interactions between biofuels and food in the market for crops and land.

On the supply side, farmers would respond to announced biofuel targets by incorporating the expected increases in crop demand into planting decisions. Potential farm level responses include changes in crop mix, crop rotation and management, livestock management, and cropland expansion, among others. The incremental cost of these responses, along with farm and biofuel support policies, determines the extent to which domestic supply can respond to the change in demands for the crops that are used for biofuel production.

Supply responses to the increase in biofuel production can be complicated by a number of non-biofuel related factors that are also shown in Figure 2. Unanticipated weather events, such as droughts and flooding, could disrupt crop supply expectations, leading to unexpected gaps between supply and demand. Similarly, sudden changes in agricultural trade and support policies, as observed during the period from 2006 to 2008, could create imbalances in the global crop supply chain. Thus, the global increases in agricultural prices from 2006 to 2008 coincided with the boom in biofuel production but took place in the context of severe weather-induced crop losses and direct market actions to protect domestic food supplies around the world [5,6,11]. In addition, economic variables such as interest rates, exchange rates and income growth may shift the competitive position of global agricultural suppliers and consumers affecting their ability to equilibrate supply and demand.

Given the seasonal nature of agricultural production, crop inventories play a crucial role in responding to any supply-demand gaps in agricultural commodity markets. In general, availability of crop inventories during a supply shortfall or storage capacities during times of excess supply can moderate the price implications of supply-demand gaps. Households would react to the resulting inventory-modulated market prices by a combination of changes in overall food intake, food quality, mix of food purchases, and allocation of expenditures between food and non-food items. Futures market prices would reflect changes to inventory levels and expectations about demand changes, serving as a guide for future production plans.

Figure 2. A framework for analyzing biofuel-food market interactions (adapted from Figure 4 of Rathman *et al*. [32]).



Biofuels can also affect food markets through other channels. Biofuel policy is designed to replace a portion of crude oil consumption, which in turn is expected to reduce oil use and prices. Oil consuming economies can spend the savings from lower oil prices on fuels and other commodities, including offsetting part or all of any increases in food prices attributable to the use of crops for biofuels. The net effects of these changes on households depend on the share of food and fuel in expenditures, food and fuel demand elasticities, and other market conditions. Households with high shares of food items in their expenditures would receive smaller benefits, whereas those with high shares of fuels in their expenditures would receive bigger benefits. The effects of biofuels on the oil price would also produce indirect effects on agricultural production through reductions in expenditures on fuel inputs, but depend on the energy intensity of agriculture. Similarly, the by-products of biofuel production may help to cushion the impacts of biofuels on food markets. For example, about one third of the corn used for ethanol production in the US are returned as distillers dry grains with solubles (DDGS), which is a high protein substitute for other livestock feeds. Finally, increases in agricultural prices may translate to higher returns to farming households.

Gilbert [33] provided a theoretical review of the role of commodity price booms, oil prices and biofuels, exchange rates, and monetary factors and futures markets in the 2006 to 2008 agricultural price spikes. Importantly, he showed that factors that produce changes in groups of agricultural food prices differ from those for changes in the price of specific crops. Using a CAPM-like (capital asset pricing model) agricultural price model it was shown theoretically that common shocks, generally demand driven, account for most economy-wide or aggregate price changes. Commodity supply shocks tend to be weakly correlated, and therefore have smaller impacts on prices. However, if supply shocks are common to all crops then both demand and supply shocks would be important to changes in aggregate prices. Similarly, demand shocks due to macroeconomic changes would produce larger price effects than commodity-specific demand shocks. Oil prices would affect food prices through food production costs and through the demand for biofuel feedstock. Gilbert [33] estimated that the pass-through of oil price changes to food prices is about 17% in the US, but the actual effect depends on market conditions. The second source of effects is the crop-specific demand from the recent substitution of biofuels for oil. In this regard, the correlation between the average price of WTI (West Texas Intermediate) and Brent oil prices and the IMF food price index offer a weak support, increasing from 0.043 during 2000 to 2002 and 0.199 during 2003 to 2005 to 0.287 during 2006 to 2008. Gilbert [33] showed that a depreciation of the US dollar implies a less than unit proportional response of dollar-denominated commodity prices. In addition, the exchange rate itself may contain business-cycle components in common with commodity prices, and causation may run from commodity prices to exchange rates. Finally, given that agricultural inventories are pre-determined from previous harvests the response of inventory to signals from the futures market could be delayed. This means that the effects of futures market signals could show up first in spot market prices, rather than inventory changes that could produce large increases in agricultural prices followed by sudden falls [33].

3. Review of the Empirical Literature on Biofuel-Food Market Interactions

A variety of approaches have been employed in the literature to evaluate the complex processes that govern food market changes as outlined above, and to help explain the effect that biofuels have on market dynamics. Partial and general equilibrium models are structural-type economic models which directly describe the responses of supply and demand to price changes, and which keep a strict accounting of the balances that must be maintained within domestic and international markets. The equations that define these models are based on behavioral relationships derived from economic theory, and in addition to the market-clearing conditions on supply and demand for commodities, they also impose balances that define the available incomes for consumers and the finiteness of resources that are used in production.

Partial equilibrium (PE) models used for biofuel-food market analyses are generally agricultural sector models that may be augmented with sub-models for the production of biofuels, and sometimes trade. These models, typically, do not include income and expenditure accounting/constraints, and tend to ignore important transactions that occur within the economy, such as the investments that are derived from household savings, or the revenues that accrue to the government (as well as the payments and purchases made by the government). In contrast, general equilibrium (GE) models cover the entire economy, and specify a comprehensive set of economic transactions including production, private consumption, trade, savings, investment, government consumption, and taxes/subsidies/tariffs. The comprehensive treatment of economic transactions gives GE models the advantage over other approaches in measuring the outcome of multiple, and complex, interactions within an economy. However, GE models are generally less detailed than PE models, whereas the latter may include significant detail on the few sectors of the economy that are considered (see Thompson *et al.* [34] as an example of the simulation of biofuel policy in the FAPRI model). There are many applications of full-scale PE and GE models incorporating extensive empirical data to analyze biofuel-food market interactions. Stylized equilibrium models with a few regions and commodities, usually of the PE-type, are often used to provide empirical illustrations of the theory in many studies.

The food market implications of biofuels are also evaluated using non-structural economic models. These models consist of econometric or reduced-form equations, rather than behavioral equations derived from economic theory. The most common types of non-structural models in the biofuel-food market literature are vector auto-regression (VAR) models. VAR-type models are linear, multi-equation systems in which each variable is specified as functions of own time lags and those of other variables.

We review several existing studies on the food market implications of biofuels based on the above two broad modeling frameworks, but note that the distinction between structural and non-structural models is not strict. Parameters of equations in structural models are often obtained from the literature, and in many cases the model itself may include a combination of reduced-form and structural equations. Variables and equations in non-structural models are also usually selected, and parameters may be constrained, based on economic theory. The studies reviewed here were obtained through a search of the literature to identify the most recent studies that attempt to quantify the role of the different factors driving global food market changes. Below, we summarize the findings from these studies, for the purposes of brevity. For a more detailed discussion of each study, the interested reader is referred to the supplementary material that is appended to this article.

3.1. Summary of Biofuel-Food Market Analyses with Structural Economic Models

Structural economic models are typically used to evaluate the impacts of biofuels on price levels, supply and trade in agricultural commodities, as well as their welfare impacts. Hochman *et al.*, Ciaian and Kancs, and Chakravorty *et al.* simulated the role of biofuels with multi-market equilibrium models [35–37]. Results of simulations with full-scale GE and PE models were summarized by

Zhang *et al.* and the US Government Accountability Office (GAO) [38,39]. More recents studies using full-scale GE and PE models include Timilsina *et al.*, Al-Riffai *et al.*, Oladosu *et al.*, Mosnier *et al.*, and Chen and Khanna [40–44]. Studies by Babcock, Tyner *et al*. and Durham *et al.* evaluated the role of flexible biofuel mandates in coping with periods of spikes in agricultural prices [24,25,45]. De Hoyos and Medvedev [46] evaluated the effects of the 2006 to 2008 agricultural price increases on household welfare and the role of biofuels. Bouet and Debuquet [47] illustrated the role of direct policy interventions in the context of a food crisis. A main result from many of these studies is that the production of biofuels leads to increases in the production and prices of agricultural commodities. However, the types and grouping of agricultural commodities are not uniform across studies, and estimates of changes in production and prices vary significantly.

Estimates of the impacts of biofuel policy on the production of grains, sugarcane and oilseeds, which are the crops most commonly included in these studies, range from 1% to 51% for corn, 1% to 95% for oilseeds, and 1% to 147% for sugarcane [38–40,42,43] reflecting the different types of models, data, scenarios, and parameters. In studies with some detail in their agricultural commodity categories the production of a few crops and livestock are found to decrease slightly [40–42,46]. The range of estimated changes in agricultural prices is almost as wide as for production at less than 1% to 84% for corn, oilseeds and sugarcane [37–44,46]. However, the upper part of the range of production and price changes are due to only a few models [38,44]. The review by the US GAO and results from most recent studies generally report production increases of less than 15% across crops, and price impacts of less than 20% [35,37,39–43]. Results from a few studies allow an estimate of the elasticity of corn/food price with respect to increases in corn ethanol production, and indicate a value of about 0.2 [37,43].

De Hoyos and Medvedev [46] estimated that the 74% increase in the international food price index between 2005 and 2007 was associated with a range of 2% to 60% increase in prices across the world. The corresponding average urban food price increase was about 4.1% in the developing world, with a range of −0.5% to 14%. A simulation to examine the role of biofuels by De Hoyos and Medvedev [46] estimated that world prices of agricultural goods increased by 10% relative to 2004 and by 5.6% relative to the baseline, with an increase of 2.2% in average consumer prices for food commodities. Similarly, the review by the US GAO [39] found that the average retail food price implications of biofuels are small, even when increases in agricultural prices are significant, pointing to the role of intervening factors on the supply chain between agricultural production and food consumption [39]. Apart from results that discuss the impacts on finished commodities, such as vegetable oil, most of the remaining studies do not report the food demand side implications of biofuels separately.

A few studies provide trade results and tend to find that biofuel policy leads to significant changes in the global trade of agricultural commodities [37,40–43]. The quantitative estimates of trade impacts are generally in the range of ±1% to ±10%; although at least one study suggested that US food exports would decline by a large amount [37]. Hochman *et al.* [35] evaluated the role of crop inventory, demand, energy price and exchange rate shocks. Relative to 2001, and without inventories, corn prices rose by less than 10% in 2007 under the biofuel shock, by 20% under the demand shock, by 9% under the exchange rate shock, and by 3%–4% under the energy price shock. Inventory was found to reduce the change in commodity prices from these shocks by as much as one-third, and smaller elasticities of supply and demand produced additional commodity price increases of up to 5%.

Two studies that examine the role of flexible US biofuel mandates as a way to respond to the 2012 drought both conclude that a waiver would not produce significant reductions in ethanol production [24,25]. Specifically, they both estimate that corn prices would decline by about 6%. Durham *et al.* [45] estimated that a full waiver of the EU biofuel mandates and supports at the beginning of a price spike would reduce the increase in the prices of corn and wheat by between 7% and 40%, depending on which grains are directly affected by the shock. A major difference between the Babcock and Tyner *et al.* [24,25] studies and the Durham *et al.* [45] study is that the former studies examined market driven changes in biofuel blending under a waiver of the mandates, whereas the latter study simulated mandatory reductions in biofuels blending. In addition, Babcock and Tyner *et al.* [24,25] accounted for flexibilities in the implementation of the US biofuel mandates through accumulated RIN (renewable identification number) credits.

3.2. Summary of Biofuel-Food Market Analyses with Non-Structural Economic Models

Non-structural economic models are usually estimated with econometric methods either to evaluate parameters that could be used in equilibrium and other simulation models, or to gauge the strength of relationships among variables. Zhang *et al.*, Ciaian and Kancs, Cha and Bae, Qui *et al.*, Nazlioglu and Soytas, Natanelov *et al.*, Nazlioglu, and Harri *et al.* [16,36,48–53] used VAR-type models to evaluate the interrelationship among energy, agricultural commodity prices, and other variables. As with equilibrium models the types and categories of agricultural commodities considered vary, and only a few studies directly include biofuels in their analyses [16,48]. However, the other studies are relevant due to the close link among biofuels, oil and agricultural commodities and because they provide insights into the role of non-biofuel factors in food markets. The relationship between agricultural and energy commodities is generally found to be weak, but most studies estimate significant short-run, and sometimes long-run, relationships between oil prices and the prices of specific commodities, including biofuel, corn, soybean and sugar [36,48,50–52].

Short-run causality tests tend to find either neutral or bi-directional causality between oil prices and agricultural prices [16,50,52], whereas long-run causality tests find uni-directional causality from oil to a few crops, mainly corn and soybeans, especially when the model is estimated using data for the last few years [36,50,52,53]. Ciaian and Kancs [36] interpreted this as indicating a role for biofuels, since corn and soybeans are major inputs into biofuels production. In one study [16], sugar was found to be causal for oil and other agricultural prices, and this was explained as capturing the role of sugar as a large input for world ethanol production, its competition with corn-based high fructose sugar, and the effect of recent economic growth on the demand for sugar. One study [51] found long-run uni-directional causality from agricultural to crude oil futures prices, with bi-directional causality only between crude oil and soybeans futures prices. These results run counter to findings from most of the remaining studies reviewed here, and may have to do with the use of futures prices in the analysis. Biofuel prices are found to have small effects on agricultural prices [16,49]. Nazliogu and Soytas [50] and Harri *et al.* [53] include the exchange rate in their models and both found the oil price to be causal for the exchange rate. The study by Nazliogu and Soytas [50] also found a negative long-run relationship and bi-directional causality between the exchange rate and agricultural prices.

Variance decompositions are performed in a few VAR-type studies to examine the relative contribution to the variation in a given variable from own and other variable innovations over time. In Zhang *et al.* [16] oil price shocks contributed 78% and 15% to the variation in gasoline and ethanol prices, respectively. Corn price shocks contributed 24% and 12% of the variation in soybeans and wheat prices, sugar price shocks contributed 11% of the variation in soybean prices, whereas ethanol price shocks contributed less than 0.05% to the variation in agricultural prices. Cha and Bae [48] found that the combination of oil price and corn export demand shocks explained 36% of the historical variation in corn prices during 2007 and 2008. Oil price shocks explained 66% of the forecast error variance in the use of corn for ethanol and 38% for corn prices. Qui *et al.* [49] found that an ethanol demand shock accounted for only 4% of the variation in corn prices in both the short- and long-run (about 5 years). Qui *et al.* [49] also found that a shock to real economic activity produces positive short- and long-run increases in corn prices, but real economic activity contributed only 0.3% to the variation in corn prices in the short-run and about 2.7% in the long-run. Ciaian and Kancs [36] calculated price transmission elasticities from oil to agricultural commodities, and *vice versa*. The price transmission elasticity is defined as the ratio of the change in the prices of other commodities to the change in the price of the commodity being shocked. For oil to agriculture, the price transmission elasticities were 0.15 for corn and wheat, 0.28 for sugar, 0.17 for soybean, and less than 0.06 for all other commodities. Price transmissions from agricultural prices to the oil price were generally one-order lower and negative for corn and tea.

Gilbert [33] and von Braun and Tadesse [54] estimated multi-equation regression models to examine the role of oil prices and other macroeconomic variables on food commodity prices. Irwin and Sanders [55] conducted a comprehensive review of the literature on the role of index funds in the recent commodity price spikes. The impact of exogenous dollar depreciation on the food price index was estimated at about 15% in Gilbert [33]. Von Braun and Tadesse [54] estimated that excessive speculation and oil prices have significant impacts on price returns for four crops (corn, wheat, soybeans and rice). Irwin and Sanders [55] showed that available studies are at best indeterminate on the notion that commodity index investments caused a price bubble in commodity markets. Irwin and Sanders [55] also pointed to inconsistencies between observations and the predictions of a bubble induced food price spike including: (1) commodity inventories were declining through most of 2006–2008 rather than increasing as would be suggested by a bubble; (2) speculation activity was not excessive relative to hedging behavior; (3) the effects of index funds were found to have differential, instead of similar effects, across markets.

3.3. Sources of Differences in Estimates of the Impacts of Biofuels on Food Markets

The range of quantitative estimates of the impacts of biofuels on agricultural supply and prices from the studies reviewed in this study is wide. A major reason for this wide range is the difficulty of accounting for all the potential factors and linkages implied by Figure 2 in any particular study. Another reason is that there are fundamental differences in the types of models that have been used to analyze biofuel-food market interactions. Each type of model is suitable for addressing different aspects of food security, and the role of biofuels. Equilibrium models are particularly suitable for simultaneously estimating the changes in agricultural/food supply, demand, trade and prices under biofuel policy. Although the behavioral specifications in these models are useful in disentangling the impacts of individual factors, the practice of calibrating these models to a single year of data means that a considerable amount of refinements would be needed to replicate empirical observations over time. VAR-type models are suitable for evaluating the dynamic interactions, causality, and volatility of a given set of variables. These features make VAR-type models useful for evaluating the causes and volatility of agricultural/food market prices based on the historical data. However, their non-behavioral and largely linear specifications limit the extent to which the impacts of individual factors and linkages can be identified. So far, these types of models have been used mostly to evaluate the interaction of agricultural and energy prices, as well as exchange rates. Also, while econometric or reduced-form models can be used for forecasting purposes the resulting forecasts are tied to the relationship among predictor variables as captured in the estimated model. Unless these relationships remain valid over the forecast period, the forecasts are likely to be misleading. The strengths of the two categories of models can be complementary to one another. The study by Cianian and Kancs [36], which employed both PE simulation and cointegration analysis, provides an example of this complementarity. Although the two approaches were largely independent in their paper, the theoretical exposition served as a common basis for the results.

Zhang *et al.* [38] highlighted a number of factors that may explain the wide range of crop production and price results obtained from PE and GE models used for simulating the impacts of biofuels. These include model structure, scenario design and other specification assumptions/choices. There is a basic dichotomy between partial and general equilibrium models. By design, PE models are unable to comprehensively account for influences arising from or transmitted to the wider economy beyond the sectors included in the model. Thus, estimates from a partial equilibrium model are expected to be larger in magnitude than from a general equilibrium model, if sectors in the PE model were similar to corresponding sectors in the GE model. However, this does not hold as a general rule because results obtained from any particular model also depend on data, constraints and other factors that affect the model solution. Another important source of differences in estimated impacts is the geographical scope and detail of different models. External trade effects, crucial to the food and other implications of biofuels, are best captured in models with a global scope. National models often account for trade through excess supply/demand functions but these are incomplete representations of the rest of world responses to domestic biofuel policies. Even in global models, nations are usually aggregated into regional groups. In this case, it is important to define these regions in a way that combines nations with similar roles in the global economy, and with respect to the policy under consideration.

A number of assumptions in the literature appear crucial to the estimated impacts of biofuels on food markets, regardless of the model structure and scenario design. These include assumptions about land use/supply, crop/livestock yields, biofuel by-products, crop inventories, the relationship between biofuel and oil markets, and income effects. These factors are discussed in a bit more detail below.

Specification of land use/supply can be expected, and is in fact, one of the crucial determinants of estimates of the food market implications of biofuels. As noted by Zhang *et al.* [38] the land supply function in the LEITAP model [56] appears to be the main difference accounting for its lower estimates of the food market impacts of biofuel compared to those from similar models. More recent studies that show small agricultural price impacts of biofuel policy generally allow for the endogenous expansion/contraction of agricultural land in their simulations, whereas those that do not allow for agricultural land expansion tend to produce high production and price effects in food markets. In addition, depending on whether land is constrained or available in the domestic or foreign markets or both, global and multi-regional models may generate different land use change effects in the two markets, and globally. For example, Chakravorty *et al.* [37] predicted a 5% increase in food prices in a simulation that allowed global cropland to expand. However, because no land expansion was allowed in the US their results also suggested that 41 million hectares of land currently used for food production would be diverted for biofuel production, leading to a 25% decline in US agricultural production and a 70% decline in exports. Given the much higher productivity levels in the US, domestic, rather than foreign, expansion of agricultural land for biofuel production would have produced smaller declines in exports and diversions of agricultural land. The latter results are found in global GE models with endogenous domestic and foreign land expansion functions, such as MIRAGE, GTAP-DEPS and LEITAP [41,42,56].

The role of assumptions about crop/livestock yields, crop inventories and by-products of biofuels production in the food market impacts of biofuels are qualitatively similar to those for land. Yield, being a multiplier of land use in agricultural production, would be expected to have similar food market impacts as land use/supply assumptions. The simulations in Hochman *et al.* [35] showed that the availability of crop inventories produce smaller price increases from biofuel and other shocks. Most of the remaining studies did not explicitly examine the role of inventories.

Crude oil prices, the relationship between biofuel and oil markets, and income effects, affect food markets through both supply and demand channels. Many of the equilibrium models used for biofuel analyses specify crude oil prices exogenously, but a few allow oil prices to be determined endogenously [42]. Displacement of a portion of the global use of oil by biofuels can affect oil prices, which in turn has implications for the food market. These effects are ignored if oil prices are specified exogenously. Furthermore, many models impose a tax on petroleum, thus raising its domestic price to accommodate biofuels. Exogenous and/or rising petroleum prices not only mute the beneficial effects of biofuel policies on the global oil market, but also places the burden of adjustments on other sectors of the economy, including food markets.

Most non-structural economic models focus on the dynamic interaction of energy, agricultural prices and other macroeconomic variables. Thus, differences in the results from these models are mainly due to differences in the data range and frequency, the type of agricultural commodities included, and the types of statistical tests for short-/long-run relationships among variables. These studies generally include time series data on oil and agricultural prices between 1985 and 2010 but the data frequency range from weekly to annual. Approaches for conducting statistical tests are also important in the results from these studies. For example, studies that use both linear and non-linear tests find that the latter tends to identify significant relationships among oil and agricultural prices in cases where the former suggests a neutral relationship [51,52]. The importance of differences in data and statistical tests is further highlighted by Irwin and Sanders [55] which showed that an almost equal number of studies with a significant and an insignificant role for index investment funds can be identified in the literature.

4. Conclusions

Conventional biofuels production in the US is almost at the maximum target set under the RFS2. Although slow, the transition to second generation or advanced biofuels has started. Advanced biofuels are to be produced mainly from non-food cellulosic biomass. Still, the role of biofuels in food markets remains a policy issue for three reasons. First, analyses of the spike in agricultural prices between 2005 and 2008, coincident with rising biofuel production, and between 2010 and 2011 have yet to produce a clear-cut estimate of the role of biofuels. Second, in 2012 the US agricultural sector experienced the most extensive and severe drought in several decades. Given that increases in the production of conventional biofuels in the US is restricted by the RFS2, the focus of the discussion is on the role of potential changes to biofuel policy in coping with the food market implications of the drought. Lastly, some of the feedstocks for second generation biofuels require land, water and other resources that may compete with agricultural production.

The current study reviewed the existing literature on the role of biofuel and non-biofuel factors in recent global food market changes. There are a number of insights from this review:

- Initial conclusions attributing most of the spike in global food prices, particularly from 2005 to 2008, to biofuels have been revised.
- The transmission channels of the impacts of biofuels to food markets are confounded by a host of non-biofuel physical and economic factors, and their impacts should be isolated in order to adequately evaluate the role of biofuels. The role of these non-biofuel factors in the global food price spikes of the 2000s remains unclear.
- Existing estimates of the national, regional and global impacts of biofuels on food supply and prices span a wide range.
- International food price spikes are associated with a wide distribution of country-level food price changes, which produce disparate household welfare impacts around the world.

The wide range of the estimated impacts of biofuels on food market from different studies can be partly explained by differences in modeling approaches, geographical scope, and assumptions about a number of crucial factors. These factors include: (1) domestic/global availability of land for agricultural expansion; (2) response of oil prices to biofuel policy; (3) crop/livestock yields; (4) availability and management of crop inventories.

The potential role of biofuels as a "virtual grain store" that could be used to cope with unexpected gaps in the supply and demand for crops is a relatively new area of inquiry. The three papers reviewed on this subject suggest that flexible biofuel policies could contribute modestly to reducing spikes in food prices from unexpected supply shortfalls. Two of the studies focused specifically on the 2012 drought in the US, and concluded that the existing flexibility in the RFS2 implementation is capable of producing almost the same reductions in corn prices as a waiver of the ethanol mandates in 2013 [24,25]. However, as highlighted by Durham *et al.* [45] there are several important remaining issues, including the assumption of zero cost to oil and biofuel markets from a flexible mandate, the impact of panic buying and export restrictions, and the costs and benefits associated with different mechanisms for implementing flexible mandates.

Finally, this review suggests a number of missing areas in the existing literature that are important to the impacts of biofuels on food markets. Many studies, particularly the non-structural economic models that are estimated with historical data, do not adequately isolate the influence of crucial non-biofuel factors, such as macroeconomic changes and adverse weather conditions when evaluating the role of biofuels [57]. Only a few studies have evaluated the role of second generation biofuels in food markets [42-44], or accounted for the real income effects of biofuels through changes in oil prices [42]. Analyses with VAR-type models need to be extended to incorporate non-price variables related to biofuel policy. There is also a need to harmonize assumptions about a number of factors that drive the estimated effects of biofuels on food markets, including domestic and global land availability, crop/livestock yields, crop inventories, and by-products from the production of biofuels. Finally, results on the impacts of biofuels on food markets need to be standardized so as to make these estimates more comparable across studies.

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