THE IMPACT OF BIOFUELS ON COMMODITY FOOD PRICES: ASSESSMENT OF FINDINGS

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For years, agriculture has provided most of the fuel for vehicular transportation. The discovery of the internal combustion engine and the use of oil derivatives for vehicular fuel led to an increased reliance on fossil fuels for transportation energy in the 20th Century. However, concerns about availability of fuels, balance of trade, and climate change led to the introduction of biofuel programs in the United States, Brazil, European Union (EU), and other countries. The impacts of these programs and the relationship between the food and fuel markets have become major topics of economic research.

This paper summarizes the main findings of alternative lines of research on the relationship between the food and fuel markets and identifies gaps and quandaries that warrant further research. This is not meant to be a complete survey, and it emphasizes several of our studies within the broader literature. The paper distinguishes between two bodies of literature: one on the relationship between food and fuel prices and another on the impact of the introduction of biofuel on commodity food prices. While biofuel prices do not seem to affect food-commodity prices, we explain why the introduction of

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biofuel does. Moreover, biofuels have not been the most dominant contributor to the recent food-price inflation and different biofuels have different impacts.

Impacts of Biofuels Prices on Food-commodity Prices

One of the major constraints associated with the introduction of biofuel is its impact on agricultural commodity prices as higher commodity prices may have an adverse effect on the poor (Rajagopal et al. 2007). Time-series econometrics provides a means to investigate the dynamic linkages between food and fuel prices. Studies applying these tools suggest that the relationship between the prices of fuels and food commodities depends on location (United States, Europe, or Brazil), the food and fuels considered, the modeling specification, and the time dimension of the data (daily, weekly, or monthly). Because the time-series models "let the data speak" and do not rely on economic modeling, we will present these findings first and then use economic reasoning to interpret them.

Serra et al. (2011) uses autoregression analysis to identify the relationship between corn, ethanol, gasoline, and oil prices in the United States, using monthly data from 1990-2008. They found that the four prices are related in the long run through two cointegration relationships: one representing the equilibrium within the ethanol industry and the other representing the equilibrium in the oil-refining industry. The ethanol market provides a strong link between corn and energy markets, and the price of ethanol increases as the prices of both corn and gasoline increase. An increase in the prices of either gasoline or ethanol leads to future increases in the price of oil. The analysis reveals that, frequently, the price of ethanol was linked strongly to the price of gasoline. However, during periods of relatively high corn prices, the price of corn was the dominant of factor. This complements the results of Taheripour et al. (2010) and Hochman, Sexton, and Zilberman (2008), who suggest that the corn biorefineries may suffer losses when corn prices are high if the price of ethanol does not fully adjust to the rise in the price of corn.

Zhang et al. (2009) applied multivariate autoregression estimators to investigate the volatility of the wholesale prices of corn, ethanol, soybeans, gasoline, and oil in the United States between March, 1989, and December, 2007. They found that ethanol and oil demands are derived from the demand for vehicle fuel, and gasoline prices influence both the price of ethanol and oil. They also found a strong link between agricultural commodity and ethanol prices. Increases in ethanol prices have short-term, but not long-term, effects on agricultural commodity prices.

A study on Brazil by Serra, Zilberman, and Gil (2011) used weekly international crude oil and ethanol and sugar prices, observed from July, 2000, to February, 2008, to assess volatility spillovers in Brazilian ethanol and related markets. They found that the ethanol prices are positively related to both sugar and oil prices in equilibrium, and price dynamics indicate substitution between oil and ethanol. Markets transmit the volatility in both the oil and sugar markets to ethanol markets, but there is minimal transfer of volatility from the ethanol market to the oil and sugar markets. Another study on Brazil by Serra (2011) uses nonparametric correction to time-series estimations to assess the volatility between energy and food prices in Brazil. It supports the long-run linkage between ethanol and sugarcane prices and finds that crude oil and sugarcane prices lead ethanol prices and not vice versa.

The study by Zhang et al. (2010) used monthly price data for corn, rice, soybeans, sugar, and wheat as well as ethanol, gasoline, and oil between 1981 to 2007 to estimate the linear relationships that cointegrate these price series. They found statistically significant long-run relationships between oil and gasoline prices and gasoline and ethanol as well as between the prices of three groups of agricultural commodities. While oil prices influence gasoline prices, which, in turn, influence ethanol prices, fuel prices do not significantly affect food prices.

While most studies have investigated U.S. and Brazilian biofuels data, Kristoufek, Janda, and Zilberman (2011) analyzed correlations between a wide array of food and fuel commodity prices in the United States and EU using Bloomberg ticker data between 2003 and 2008. The results indicate that the dynamic interaction between different commodities varies significantly when analyzing weekly, monthly, and quarterly data. For the less-noisy quarterly data, the results indicate more correlated dynamic behavior between commodities at the same (or a close) geographic location. The analysis found significant dynamic linkages between food prices as a group and fuel prices as a group with biofuels serving as the link between these markets.

The literature linking the food and fuel prices suggests that ethanol prices throughout the world are affected by both food and fuel prices. But the linkage between ethanol prices and food prices is rather weak, and there is very limited transmission of shocks between fuel and food prices. These results led Zhang et al. (2010) to question the concerns about the impacts of biofuel on food market. These results did not find that food prices respond significantly to changes in fuel prices and, in particular, changes in biofuel prices.

There are two reasons why the feeble response of food prices to biofuel prices does not imply that the introduction of biofuel does not affect food prices. First, the studies on the relationship between fuel and food prices estimate coefficients of *marginal* effect while most of the literature on the impacts of biofuel on food prices, which we will discuss in more detail below, aims to assess *total* price effect of diversion of commodities from food to fuel production. In other words, the literature is interested in the impact of the overall biofuel production on food prices, not the impact of biofuel introduced during the last six-month period. But the more substantial reason is that, while theory predicts that the introduction of biofuels is likely to raise the price of food when land is fully utilized, the impact of a change in the price of biofuel on food prices is not apparent a priori. The directional effect of a change in the price of biofuels on the price of food commodities can be predicted only when the cause of the change in food prices is specified (see figure 1).

Figure 1 presents a price-setting mechanism for biofuel. The biofuel demand curve is assumed to be negatively sloped, and demand is assumed to increase (shift to the right) as the price of gasoline increases. The biofuel supply curve is assumed to be positively sloped, and biofuel supply is assumed to increase (the curve shifts to the right) as either the price of food is decreasing or the biofuel-refining capacity is increasing. Let the initial demand for biofuel be denoted by D_0 and the initial supply be denoted by S_0.

Thus, there is an internal equilibrium at point A. If food prices increase, the supply of ethanol shifts from S_0 to S_3 and a new equilibrium (point G) will be attained and the price of ethanol will increase. If ethanol production capacity is expanding (more refineries are being built), the supply moves from S_0 to S_1 and the new equilibrium is at point B with a lower price. We also assume that the demand for ethanol declines when gasoline is decreasing (shifting from D_0 to D_1), and the equilibrium will move from point A to point C in figure 1.

It is easy to verify from figure 1 that both an increase in the price of gasoline (shifting demand upward) and an increase in the price of food (shifting supply upward) will lead to increases in the price of biofuel and, thus, the predictions of the model are consistent with the results of the empirical studies.

Now, consider the impact of changes in the price of ethanol on the price of food. There are two possible reasons for changes in the price of ethanol: (1) change in demand for ethanol due to an increase in the price of gasoline and (2) change in the supply of ethanol (not resulting from a change in the price of food) because of a change in the refining capacity. When a reduction in the price of gasoline causes a change in ethanol price, the demand for ethanol shifts from D_0 to D_1 in figure 1 and results in a shift of the equilibrium from A to C so that the change in the price of ethanol is negative and is denoted by $\Delta P_E^{AC} < 0$. But this reduction in price of ethanol also reduces biofuel production and biofuel acreage. Therefore, if land is constrained, more food is produced so that the change in the price of food is negative and denoted by $\Delta P_F^{AC} < 0$. If the cause of the biofuel price change is a gasoline price change, the direction of the change in the price of food is the same as the direction of the biofuel price change that caused it.

Now, consider the case where ethanol supply was expanded by adding a new refining capacity. In this case the supply curve shifts from S_0 to S_1, leading to a new equilibrium at B and a decline of the price of ethanol denoted by $\Delta P_E^{AB} < 0$. The expansion of ethanol results in the transition of land from food to fuel and, thus, increases the price of food so that the change of the price of food is $\Delta P_F^{AB} > 0$. If the cause of the biofuel price change is an increase in refining capacity, the direction of the change in the price of food is in the opposite direction of the change in the price of biofuel. Under one plausible scenario, lower ethanol prices will lead to the increase food prices and, under another, they will lead to lower food prices. Thus, the directional impact of a change in ethanol prices on food prices is not straightforward. This explains the inconclusive results obtained in many of the food and fuel price series studies.

Note that biofuel prices are also affected by various polices and regulations. The quantity of biofuel produced has to exceed the mandate (M in figure 1) and cannot exceed a volume determined by the blend wall (W in figure 1). The mixture of regulations and constraints affecting the biofuel markets may further complicate the directional effect of changes in biofuel price on food prices. While there is ambiguity about the impacts of changes of biofuel prices on food prices, at least in the short run, reallocation of land from food to fuel production will lead to higher food prices.

The uncertainty about the directional linkages between biofuel and food markets raised by the literature on food and fuel prices, and its emphasis on distinguishing between short term and long term patterns, inspires us to further evaluate the standard assumptions about the relationship between biofuel production and food prices. We conclude that these relationships are likely to be different for different biofuel feedstocks and for different countries. It is useful to distinguish between countries according to the extent to which their agriculture is bounded by constraints on natural-resource availability, in particular, land and water. There is likely to be a significant difference between the impact of expanding sugar ethanol on sugar in Brazil and the impact of expanding corn ethanol in Brazil. Brazil has been using a relatively modest fraction of its arable nonforestland intensively (Mathews and Tan 2009). In 2008 it had 77 million hectares of crop production, but close to 260 million hectares of arable land have not been utilized intensively. Brazil biofuel production can be expanded without affecting sugar production, especially in the longer run. Much of the expansion of the biofuel industry has been aimed at producing biofuels, and ethanol farmers may introduce a capacity to produce both sugar and ethanol in periods with relatively high sugar prices. It seems that, at least theoretically, the introduction of the sugar ethanol industry on new lands may actually reduce the price of sugar if there is an effort to utilize some of the new sugarcane capacity for sugar instead of biofuel.

Because of the land constraints faced by U.S. farmers, the expansion of corn ethanol is more likely to reduce the supply of agricultural commodities for food and increase their prices. But, even here, the increase in biofuel may not be a zero sum game and may lead to a lower reduction in food supply than implied from the allocation of corn to ethanol, which would reduce the increase in the price of corn for food. The extra profits generated by corn ethanol will lead farmers to expand their farmed land (sometimes taking land out of the Conservation Reserve Program and farming marginal lands), invest in equipment, and induce farm-input manufacturers and researchers to develop new products and technology that will increase corn supply. Cochrane's (1993) analysis of the history of U.S. agriculture suggests that periods of high farm prices in the past were followed by investment that increased supply and enhanced productivity, which may be one of the impacts of biofuels.

The research on the impacts of the linkages between fuel and food prices, while insightful, has a limited capacity to assess the impacts of biofuel on food prices and, in particular, on the recent increase in prices of agricultural commodities. This has been done frequently using theory-based simulations.

The Impact of Biofuel on Food Prices

The large body of literature that relies on simulation to assess the impact of introduction of biofuel on food prices has applied several approaches. The first is *partial-equilibrium elasticity analysis* that assesses the impact of biofuel on food prices by using elasticities to assess the price changes resulting from the diversion of the supply from food commodities because of biofuel. A simple graph of this approach is provided in figure 2. The initial demand, before biofuel, is D_F then, after biofuel, the total demand is D_{F+B}. The initial supply is S_0 but, after some adjustments, the supply may move to S_1. The introduction of biofuel may lead to an increase in price from P_A to P_B but, if supply is adjusted, than the price change is from P_A to P_C. In the case of sugarcane, for example, the introduction of biofuel leads both to increased demand for sugarcane as well as an increase in supply (Goldemberg et al. 2004). Thus, the percentage price increase due to the introduction of biofuel on sugarcane is $\left(P_C - P_A\right)/P_A$. In principle, if the supply expansion because of biofuel is substantial, this ratio may be negative. In the case of corn ethanol, the impacts of the introduction of biofuel are spread across multiple markets and are more complex when both corn and soybeans, for example, are used for biofuel. An early application of this elasticity approach is done by Rajagopal et al. (2007), who emphasized that the uncertainty about the magnitude of both the supply and demand elasticities led to a broad range of values of estimated impact. To avoid the complexity of multiple food products, Roberts and Schlenker (2010) reduced field crops to one core product calories and estimated demand and supply to evaluate the impact of ethanol subsidies and mandates on price and the global quantity of calories and the resulting consumers' and producers' surplus. Their analysis implies that U.S. biofuel mandates will increase the price of food by 30 percent and, if a third of the biofuel calories are recycled as feedstock for livestock, the predicted price increase scales back to 20 percent. The beauty of Roberts and Schlenker's (2010) results is its elegance, and the results are reasonable. But the price of simplicity is that not all calories are alike, and there is a big difference between calories produced for human food products versus animal feed. Moreover, policy makers are aware that other factors beside biofuel may cause food-price inflation and, frequently, are more interested in the relative importance of biofuel compared to other factors, which requires a more detailed analysis.

A second approach is the *ad-hoc multifactor analysis* presented by Mitchell (2008), who analyzed the rapid food-price rises between 2002-2008 and, using economic logic and results from published studies, reached quantitative conclusions. He found that higher energy prices as well as the weak dollar caused food prices to rise by about 35-40 percentage points from January, 2002, to June, 2008, which explains the 25-30 percent of the total price increase. Most of the remaining 70-75 percent increase in food-commodity prices was due to biofuels and the consequences of low grain stocks, large land-use shifts, speculative activity, and export bans.

A third approach is the *byproduct of indirect land-use analysis*. There is a growing concern that the introduction of biofuel would lead to a rise in the price of food, which, in turn, would lead to an expansion of agricultural land use and an increase in greenhouse-gas emissions. Estimates of the indirect land-use effects are derived for policy analysis, and the impact of biofuel on food prices is a byproduct of a larger modeling exercise aiming to quantify the indirect land-use effects of biofuel. Khanna (forthcoming) provides an overview of the large literature on the indirect land-use effects, and Chakravorty, Hubert, Nostbakken (2009) survey some of it within the food versus fuel literature. The indirect land-use models rely on various techniques, including programming models, partial-equilibrium models, and general-equilibrium models, that operate at different degrees of detail. The literature considers both past impacts and predicts future effects emphasizing the role of policy and markets while taking into account second-generation technologies. Chakravorty, Hubert, Nostbakken's (2009, p. 660) survey concludes that, with the increased price of fossil fuels, the diversion of land to produce first-generation biofuels "…may increase (the price of food commodities) by 65-75% by the year 2020. However, when more advanced second-generation biofuels that use less land are introduced, these figures decline to 45-50%."

While much of the literature emphasized analyzing the impacts of biofuel on agricultural commodities, Al-Riffai, Dimaranan, and Laborde's (2010) general-equilibrium analysis assessed the impact of EU and U.S. biofuel mandates on final food prices. They found that EU biodiesel mandates have a strong effect on agricultural commodity prices. But their analysis emphasized the impact of biofuel mandates on food prices and economic welfare, and they found that the proposed EU mandates as well as other biofuel policies have relatively modest effects on final food prices and welfare.

A fourth approach is a *byproduct of comparison of alternative biofuel*. It includes studies that assess the indirect land-use effect. Using a variety of models, this approach emphasizes the comparison of policies that affect the trade-offs between various types of biofuels. It finds that policies that favor corn ethanol versus other biofuels that do not rely on diverting land from food production result in higher food-price increases. For example, de Gorter and Just (2010) emphasize the inefficiency of using biofuel subsidies and recommend reliance only on mandates to achieve biofuel targets. They further argue that the import tax on Brazilian ethanol has prevented expansion of the production of cheaper, Brazilian biofuel in favor of U.S. corn ethanol and contributed to the increase in food prices. Khanna et al. (2011) argue that changes in corn and soybean prices in the future, relative to business as usual, will depend on the extent to which greenhouse-gas emissions from biofuels are regulated by policies, such as low-carbon fuel standards or a carbon tax.

Chakravorty et al. (2010) developed a *multimarket model* to assess the impact of biofuel on fuel and food in the future, emphasizing heterogeneity of land productivity and multiple crops and the relationship between crops and livestock. Their analysis considered the future dynamics of food prices taking into account the cost of achieving biofuel mandates that require a significant increase in their use. They argue that, while biofuel standards are important contributors to the rise of food prices, they are not the dominant one. They expect that, with rising income, populations in developing countries will increase their consumption of animal products, which will further increase the demand for cereal. Thus, they expect that two-thirds of the increase in food prices will come from increased food demand because of economic growth and biofuel mandates will contribute only one-third.

Combining Several Factors

In several studies we recently attempted to assess the relative importance of various factors that contributed to the food-price increase in 2007-08. In Hochman et al. (2011), we developed a *multimarket analysis* that quantifies the impact of several factors, such as economic growth, biofuel expansion, and exchange-rate fluctuation, as well as the rise in energy costs on the prices of several agricultural commodities. In addition, we incorporated an inventory management model (based on Carter, Rausser, and Smith 2008) so, each period, the demand is met by new supply as well as inventory change. Declines in prices are associated with inventory accumulation, and increased rates of price appreciation are associated with a larger inventory reduction. We considered five crops (wheat, corn, soybeans, rapeseed, and rice) and five blocks of nations that are major producers.

The results suggest that inventories matter. The simulation model (Hochman et al. 2011) shows that, when the effects of inventory management are taken into account, the estimated overall impact on food prices of economic growth, increased energy prices, biofuel expansion, and exchange-rate fluctuations for the period 2001-2007, is roughly 12 percent smaller. During these seven years, reduction in inventories operated to slow the potential food-price increases. However, as inventories declined around 2008, the government stopped releasing inventories. This, combined with the drastic rise in energy prices and other factors, led to further increases in food prices. The study found that economic growth was the most important contributor to food-price inflation, followed by biofuel and increases in the price of fuel and exchange rates. The U.S. biofuel contributed to 20-25 percent of the increase in the price of corn between 2001-2007 and contributed to 7-8 percent of the increase in the price of soybeans. On the other end, the increase in the Gross National Product in developing countries was associated with the 30-38 percent increase in the price of corn, 29-31 percent increase in the price of soybeans, 30-31 percent increase in the price of rice, and 24-40 percent increase in the price of wheat.

One type of change that has not been emphasized in the literature addressing food-price changes is technological change, in particular, the impact of genetically modified (GM) varieties that have been adopted in corn and soybeans extensively since 1995, but their use has been heavily restricted. Sexton and Zilberman (2011) assess the impact of GM on yields of corn, soybeans, rapeseed, and cotton. They found that these impacts are bigger in developing countries than in developed countries. For example, the adoption of Bacillus thuringiensis (or Bt) cotton was estimated to increase yield by 56 percent in developing countries and 15 percent in developed countries. The adoption of GM soybeans increased yield by 30 percent in developing countries. Using these estimates under various scenarios, they found that, without biotechnology, corn prices would have increased by 15-34 percent and soybeans would have increased by 22-40 percent. The introduction of GM varieties (herbicide-tolerant varieties) allowed production on land that had not previously been farmed. These estimates do not consider the acreage expansion because of the introduction of GM varieties. Nevertheless, these effects suggest that, without an increase in crop productivity associated with the adoption of GM varieties, the impact of biofuel as well as increased income and population-growth impacts on price would have been much stronger.

Sexton and Zilberman's (2011) analysis also suggests that, if the ban on GM in Europe and Africa would have been eliminated, and GM adoption in the United States would have expanded to wheat, the order of magnitude in price effect would have been equal to that associated with biofuel. Since biotechnology is in its infancy, more favorable regulatory environments might further improve productivity and reduce prices and, thus, increase the feasibility of producing food and fuel together in a sustainable manner.

Conclusion

There is a growing interest in quantifying the impacts of the introduction of biofuel on the prices of commodity food prices. This paper argues that the time-series analysis linking food and fuel prices shows that biofuel prices are increasing with both fuels and food prices, but it also shows that changes in biofuel prices have little impact on food prices. We argue that this last result does not imply that the introduction of biofuel has minimal impacts on the price of food but that the analysis of the relationship between food and fuel prices cannot fully capture the impact of biofuel on food prices.

Reviewing findings of several lines of analysis through simulations and other theory-based computations, we conclude that introduction of biofuel may affect food prices but the impact varies across crops and locations. Furthermore, we found that the introduction of biofuel has a lower impact on food-commodity prices when biofuel production is not competing with food crops for resources, such as land and water. Thus, the expansion of sugarcane ethanol in Brazil and second-generation biofuels grown on nonagricultural lands are likely to have a much smaller impact on food prices than the expansion of corn ethanol. We further argue that the introduction of corn ethanol has had a significant impact on food commodity prices, but it is less substantial than the impact of economic growth and approximately of the same order of magnitude, though in the opposite direction, as the impact of the introduction of GM organisms.

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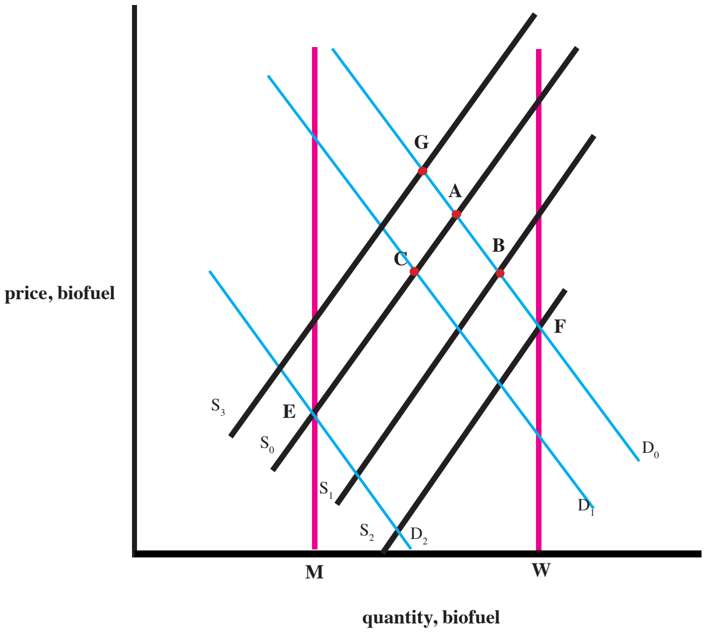

Figure 1. Determination of the price of biofuel

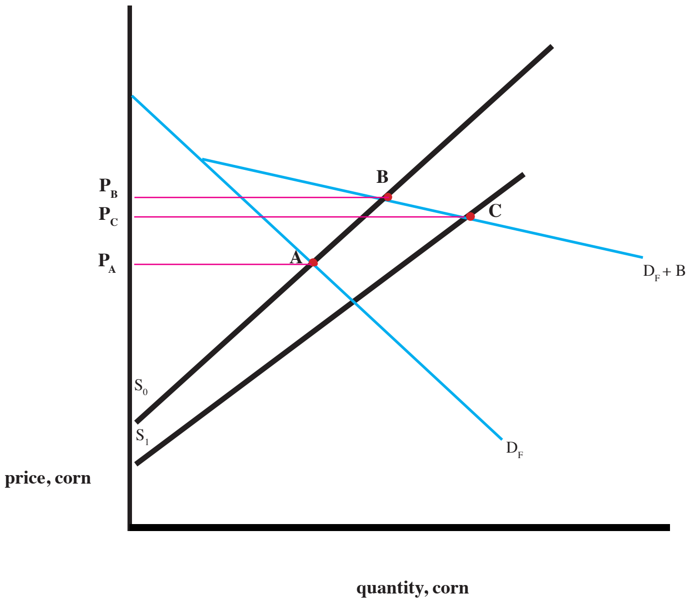

Figure 2. Biofuel and the food market