International Interlinkages of Biofuel Prices: The Role of Biofuel Policies

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Abstract

Based on their theoretical predictions, Kliauga, de Gorter, and Just (2008) and de Gorter, Drabik, and Just (2010) argue that the United States and the European Union establish the world ethanol and biodiesel prices, respectively. We test these theories using cointegration analysis and the Vector Error Correction (VEC) model. Weekly price series are analyzed for the major global biofuel producers (European Union, United States, and Brazil) for the period 2002 – 2010. Polices in the United States and Brazil appear to play an equal role in determining ethanol prices in other countries, thus only partially confirming the theoretical predictions. For biodiesel, our results demonstrate that the EU mandate impacts the world biodiesel price and thus they confirm the European Union's price leadership established in theory.

Key words: biofuels, biofuel polices, price leadership, VEC
JEL: C32, Q16, Q17, Q47

1. Introduction

The process of biofuel (ethanol or biodiesel) prices formation and their international interlinkages are important in understanding the worldwide biofuel price response to biofuel policies as well as to exogenous shocks, such as oil price fluctuations. The recent increase in the volatility of global commodity prices has attracted a lot of policy makers' attention. Governments from around the world have introduced various measures to react to this structural change in the commodity markets. The biofuel sector plays a prominent role in this respect as it is perceived to be the key factor driving recent price developments. Understanding biofuel price interlinkages also allows one to evaluate the efficiency of the biofuel policies and more specifically, to study the impact biofuel polices have on the commodity price changes.

There is a growing body of literature on the economics of biofuel policies and interlinkages of commodity prices (e.g., Balcombe and Rapsomanikis 2007; Babcock 2008; Xiaodong and Hayes 2009; de Gorter and Just 2009, 2010; Zhang et al. 2009, 2010; de Gorter, Drabik, and Just 2010; Ciaian and Kancs 2011). Theoretical studies show that the biofuel polices are the key factor affecting the biofuel prices. Given the current policies, according to Kliauga de Gorter, and Just (2008) and de Gorter, Drabik, and Just (2010) the world market price of biofuel is either (*i*) linked to the fossil fuel price adjusted by a tax credit (or exemption) in the country with a combination of the highest fossil fuel price and the lowest net tax or (*ii*) it is determined by a binding mandate if the biofuel price in the country is higher than under the case (*i*). This theory implies two empirically testable price relationships. First, if the tax credit (or exemption) drives biofuel prices, then one would observe that the crude oil price and the fossil fuel (gasoline, diesel) price in the price leading country determines the biofuel prices in other countries. Second, if the biofuel mandate determines the biofuel prices, then one would expect the biofuel price in the price leading country to determine the biofuel prices in other countries. Kliauga, de Gorter, and Just (2008) showed that the world ethanol price has historically been determined in the United States. Similarly, de Gorter, Drabik, and Just (2010) demonstrated that the European Union by its EU biofuel policy has determined the world

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biodiesel price. The main shortcoming of those two studies is their empirical approach – they do not provide a rigorous econometric test of their theory.

The objective of this paper is to rectify their empirical approach and formally test the validity of their theoretical conclusions. Notably, we examine the price leadership among the major biofuel players – the European Union (proxied by Germany), the United States, and Brazil –representing more than 90 percent of the world biofuel market.

The remainder of the paper is organized as follows. In Section 2, we briefly describe biofuel policies in the countries analyzed. In Section 3, we formulate hypotheses to be tested. Section 4 describes the data used and Section 5 presents the cointegration techniques followed. Empirical results are presented in Section 6. Finally, Section 7 provides some concluding remarks.

2. Biofuel Policies

There is a variety of policies that can directly or indirectly impact either biofuel production or consumption. The first category includes blenders' tax credits, tax exemptions, mandates, production quotas, and production subsidies targeted on biofuel production, while the second group consists of policies such as import tariffs, production subsidies on biofuel feedstocks, or research and development subsidies. Given their importance in terms of the budgetary spending and frequency of their use in many countries, we focus only on the first tree policies listed (i.e., blenders' tax credits, tax exemptions, and mandates). Furthermore, we only describe the policies used in the countries covered in the paper: United States, European Union, and Brazil.

Under a blender's tax credit, the blender receives a subsidy per gallon of biofuel blended with a fossil fuel (i.e., gasoline or diesel, depending on the biofuel). This policy is used in the United States where, currently, the blender's tax credit for ethanol is 52 cents per gallon of which 45 cents are granted from federal funds and the rest is the average state tax credit. Up to January 2010, biodiesel blenders enjoyed a tax credit of $1 per gallon of biodiesel blended with regular diesel.

A tax exemption represents a reduction in the fuel excise tax collected at the pump level in the European Union and Brazil. The economic impacts of a blender's tax credit and tax exemption are identical in a closed economy – both constitute a biofuel consumption subsidy, but differ substantially in an open economy framework.[2] The level of the tax exemption varies among the EU countries and between biofuels, but it is on a decline as governments are essentially forgoing considerable fiscal revenues from fuel taxes with this policy. For example, a tax exemption on biodiesel in Germany was reduced from 0.47 Euro per liter to 0.29 Euro per liter between 2005 and 2009. For Brazil, Kliauga, de Gorter, and Just (2008) report the average (consumption weighted) tax exemption of R$ 0.67 per liter which is approximately 2.7 times the U.S. tax credit.

A mandate is another widely used biofuel policy. In most cases it is combined with either a blender's tax credit or a tax exemption. A biofuel mandate is used in two forms: a consumption mandate (e.g., in the United States) or a blend mandate (e.g., in the European Union, where it is termed a 'target'). While the former establishes that a fixed amount of biofuel be blended with a fossil fuel, the latter requires that a fuel mix contain a certain percentage of a biofuel. For ease of implementation, the U.S. Environmental Protection Agency annually converts the consumption mandate into its blend equivalent based on a prediction of the annual U.S. fuel consumption; for instance, the blend equivalent of the U.S. ethanol consumption mandate has been set to 7.95 percent in 2011 (Reuters 2010). For comparison, a mandatory 10 percent minimum target is set in the European Union for the share of biofuels in transport fuel

[2] The reason is that once the world market price of a biofuel is established by one country (A), a tax credit or a tax exemption in the other country (B) cannot affect it, but acts as a production subsidy in the case of a tax credit and fuel consumption subsidy with a tax exemption. (Kliauga, de Gorter, and Just 2008; de Gorter, Drabik, and Just 2010)

consumption by 2020 (Directive 2009/28/EC). In Brazil, 25 percent of gasoline fuel consumption has to come from ethanol (known as the E25 fuel).

3. The Theory of Biofuel Price Formation

Theoretical studies show that biofuel polices are the key factor determining the biofuel price. For example, de Gorter and Just (2009, 2010) developed a model that explains the link between the U.S. biofuel policies – the blender's tax credit or the biofuel mandate – and the biofuel price. In their model, biofuel (ethanol) and fossil fuel (gasoline) are assumed to be perfect substitutes and differ only in their energy content. They conclude that the price of the biofuel is determined either by a tax credit or a binding (consumption or blend) mandate, but never by both at a time.[3]

Consider first a case where a blender's tax credit on ethanol, t_c, (or a tax exemption) is the only biofuel policy. Then, based on the model the ethanol market price, P_E, is directly linked to the world gasoline (oil) price, P_G, and the fuel consumption tax, t, as follows:

$$P_E = \lambda P_G - (1-\lambda)t + t_c \quad (1)$$

where the coefficient λ measures miles traveled per gasoline-equivalent gallon of ethanol relative to a gallon of gasoline.[4] An implication of equation (1) is that if the fuel tax and the tax credit do not change over time (as it has been the case in all countries included in our study for at least some time), then the volatility in the world oil price should be transmitted into the ethanol market price, provided that the blender's tax credit is binding.

Alternatively, assume there is only a biofuel mandate that dictates a certain amount of biofuel to be blended. Although the economics of a consumption mandate differs somewhat from that of a blend mandate (see de Gorter and Just 2009, 2010 for details), the common outcome of the two policies is that, unlike with a blender's tax credit, the biofuel price is not directly linked to the world oil price: the link is completely severed with a consumption mandate (because the biofuel price is determined by the intersection of the ethanol supply curve and a fixed mandate level) and it is partially severed with a blend mandate insofar as a change in the oil price impacts the fuel demand. The intuition behind this result is that the biofuel price is more determined by the biofuel supply than by the fossil fuel price for a given mandate constraint. In the case of a blend mandate, only with an inelastic biofuel supply, will the price of biofuels be strongly linked to a fossil fuel price (see Appendix).

Finally, suppose (as it is usually the case in reality) that a blender's tax credit (a tax exemption) is combined with a biofuel mandate. For a mandate to bind, the biofuel price premium (i.e., the difference between the ethanol market price with a policy in place and the gasoline market price in the absence of a biofuel policy) due to a mandate has to be greater than the amount of a tax credit – otherwise the relationship (1) holds.

So far, we have described the biofuel market price formation in a closed economy. There is, however, trade in biofuels and so a question arises as to how the world price of biofuels is established – the question of interest in this paper. Based on the theory above, Kliauga, de Gorter, and Just (2008) and de Gorter, Drabik, and Just (2010) argue that only one country's policy and market situation determines the world biofuel price and therefore either of the following situations holds (but never both):

(i) The world biofuel market price is determined by the fossil fuel price adjusted by a miles per gallon coefficient and a tax credit (or tax exemption) in the country with a combination of the highest consumer price paid for fossil fuel and the lowest net tax (the combination of

[3] A biofuel policy is said to be binding if it is determining the biofuel market price. So, for example, even if annual ethanol consumption is below the level dictated by a consumption mandate, the ethanol price can still be determined by the mandate most of the year. For details on this see de Gorter and Just (2010).

[4] For corn ethanol, $\lambda \approx 0.70$, while for biodiesel it is somewhat higher, $\lambda \approx 0.89$.

the lowest fuel tax and highest biofuel tax credit/tax exemption).

(ii) The world biofuel market price is determined by a binding mandate if the induced biofuel price is higher than under the case (*i*).

The general implication of the relationships (*i*) and (*ii*) is that the impact of biofuel policies (tax exemptions, tax credits, or price premia due to biofuel mandates) on biofuel prices are not additive: the market price of a biofuel is not determined by the sum of each country's tax exemption, tax credit, or mandate price premium.

Transportation costs and tariffs also affect biofuel prices. However, they do not affect the direction of causation of the price relationships (*i*) and (*ii*). The transportation costs and tariffs may only weaken these relationships.[5] For example, if the United States is the price leader for ethanol, then ethanol prices in other countries are likely to decrease by transportation costs and/or tariffs, or may be independent of the U.S. price if the transportation costs and/or tariffs are prohibitive.

Based on the theoretical predictions (*i*) – (*ii*) we can establish two hypotheses which we test empirically in next sections.

Hypothesis 1: *If the biofuel and fossil fuel (gasoline or diesel) price of a country determines biofuel prices (ethanol or biodiesel, respectively) of other countries, then relationship (i) holds (i.e., the tax credit (or tax exemption) determines biofuel prices*).[6]

Hypothesis 1 says that if a country's biofuel and fossil fuel price has an impact on biofuel prices in other countries, then this country is the biofuel price leader. This is because the net tax policy (on gasoline/diesel and biofuels combined) of this country provides the most favorable biofuel price at world level which will be followed by other countries. We expect that ethanol (biodiesel) and gasoline (diesel) prices of the price leader determine ethanol (biodiesel) prices in other countries. Totally differentiating equation (1) yields $dP_E/dP_G = \lambda$ which implies that the relationship between world fossil fuel and biofuel prices in the price leading country is linear and is determined only by the conversion coefficient λ. Given that λ is approximately equal to 0.7 for ethanol and 0.89 for biodiesel, the price relationship is expected to be strong if indeed Hypothesis 1 holds.

Hypothesis 2: *If a biofuel (ethanol or biodiesel) price of a country determines biofuel prices in other countries, then the relationship (ii) holds (i.e., the mandate determines biofuel prices*).[7]

Hypothesis 2 says that the mandate implemented in the price setting country determines the world biofuel prices. With a binding mandate, the biofuel prices tend to be isolated from the fossil fuel market. Based on the model by de Gorter and Just (2009), we have estimated the price response of ethanol to changes in the world gasoline price in the price setting country (assuming an exogenous gasoline price). The derivative is negative and very small, between -0.1 and -0.01 (Appendix and Table 1). In summary, if Hypothesis 2 holds, we should observe that the ethanol (biodiesel) price of the price leader influences ethanol (biodiesel) prices in other countries (because fossil and biofuels tend to be isolated) and/or that the relationship between the fossil fuel price and biofuels is negative (as per Appendix). Comparing the Hypothesis 1 and Hypothesis 2, the former implies stronger interdependencies between biofuel and fossil fuel prices. The mandate tends to isolate the biofuel and fossil fuel prices, thus reducing biofuel

[5] In principle, export subsidies may invert the causality of prices summarized in (*i*) and (*ii*). However, this type of trade policy is not applied in reality, particularly so by the major world biofuel players.

[6] Given that a tax credit (tax exemption) (and also a fuel tax) tends to be fixed over a longer period, the endogenous fossil fuel prices in the price leading country determine the biofuel prices in other countries.

[7] This follows from the fact that if the mandate determines biofuel price in the price leader country, then the biofuel and fuel markets are isolated from each other. In this case the fossil fuel price will be independent of the biofuel price.

dependence on fossil fuel price.

4. Data

Our data consist of weekly price observations for ethanol and gasoline (January, 2002 to December, 2010), biodiesel and diesel (June, 2005 to December, 2010), and crude oil for the European Union, the United States, and Brazil. The EU data are proxied by German ethanol, biodiesel, gasoline, and diesel prices extracted from the Bloomberg database, UFOP (The Union for Promotion of Oil and Protein Plants), and the EU Commission's Oil bulletin (gasoline and diesel), respectively. The U.S. Gulf ethanol and biodiesel prices come from the Bloomberg database, while the U.S. Gulf gasoline and diesel prices are from the U.S. Energy Information Administration. Finally, Brazilian ethanol and gasoline prices are for Sao Paolo (the biggest Brazilian ethanol producing state) and come from the Center for Advanced Studies in Applied Economics and the Brazilian National Agency of Petroleum, Natural Gas, and Biofuels, respectively.

5. Cointegration

Theoretical findings from the previous section suggest that fuel prices are interdependent. Applying a standard regression approach to these data would violate the exogeneity assumption of a regression equation. A general approach to analyze interdependences between endogenous variables is the Vector Autoregressive (VAR) model where the causality between the current and past values of the variables is examined. The standard requirement for the VAR estimation is the stationarity of the time series. However, even if the individual time series are not stationary a combination of two non-stationary time series may be stationary (Engle and Granger, 1987). In this special case, the time series are said to be cointegrated, i.e., there exists a long-run equilibrium relationship between them and a Vector Error Correction (VEC) model (that adds error correction features to the VAR model) can be estimated.

To test for the stationarity of time series, we use two unit root tests: the augmented Dickey Fuller (ADF) test and the Phillips Perron (PP) test. The number of lags of the dependent variable is determined by the Akaike Information Criterion (AIC). If the time series are not stationary, we employ the Johansen's cointegration method to examine the long-term relationship between the price series. This method allows us to test for the cointegration of several time series and does not require them to be of the same order of integration. The number of cointegrating vectors is determined by a lambda max test and a trace test. Both tests use eigenvalues to compute associated test statistics. The null hypothesis of the test statistics is the existence of at most r cointegrating vectors. We follow the Pantula principle in order to decide whether or not, the deterministic components (time trend and constant term) should be included in the model.

We first perform a bivariate Johansen cointegration test on the pairs of prices. Based on the patterns obtained from the bivariate case, we test for multivariate cointegration. The bivariate case ignores a possible integration of two markets through a third market, i.e., there may exist a long-run cointegration relationship that ties several markets together whereas such a relationship is not found between two markets alone (Harris, 1995)

We determine the number of lags to be included in the model. Then, we estimate a VAR model for cointegrated variables in which we include a mechanism of the error correction model. Next, we use the AIC and the LR tests. In the event that the two tests yield different results, we consider each possibility and first follow the AIC. The adequacy of our VEC model is tested by a series of tests: the Lagrange-multiplier test for autocorrelation in the residuals; the Jarque-Berra test for normality in residuals; and the stability test of the VEC model estimates.

A possible cointegration relationship between the price series, does not automatically imply a causal relationship between them. Causality tests show whether or not a country is the price leader and which countries are price followers (or it can well be the case that none of the countries dominates the others) (Ciaian and Kancs, 2011). If two variables are cointegrated, causality in at least one direction must exist. This Granger causality can be detected through the VEC model derived from the long run cointegrating vectors. Statistical significance of the differenced explanatory variables provides information about the short run causal relationships between the variables, while the significance of the lagged error correction term explains the long run causal relationships. However, Granger causality detected through F-tests and t-tests of the VEC variables may be interpreted only within the sample period. We therefore employ the Variance Decomposition technique to measure the effect of shocks to each price on the current and future values of the same and other prices. We perform a decomposition of the variance associated with each price in the VEC model caused by shocks to the other prices after 1 to 48 weeks. By this, we can examine the price relationships summarized in Hypotheses 1 and 2, i.e., we can examine which country's prices cause biofuel prices in other countries.

6. Empirical Results

To get a first impression on the strength of prices interdependence, we report the correlation coefficients in Table 2. The correlation analysis confirms a high and positive correlation (0.717) between the ethanol prices in Brazil and Europe. There is also a positive correlation between the EU and U.S. ethanol prices (0.649), as well as between the United States and Brazil (0.614). The correlation between biodiesel prices in the EU and U.S. markets is even stronger (0.969) (Table 3).

However, before making any judgments about the relationship between the prices, we first need to analyze the characteristics of the time series. The use of non-stationary time series could lead to statistically significant results due to a spurious regression. Based on the Dickey Fuller and Phillips Perron tests, all time series are non-stationary. We achieved stationarity by taking first differences of the series.

Next, to be able to test for interdependencies between prices, we examined whether there exist a cointegrating vector among fossil fuel and biofuel. The results show that gasoline and ethanol prices are cointegrated, except for two price pairs: EU – Brazilian ethanol price, and EU ethanol – Brazilian gasoline price (Table 4). All the ethanol and gasoline prices are strongly cointegrated with crude oil prices with an exemption of the relationship crude oil – EU ethanol. Both the trace and the likelihood ratio tests reject the absence of cointegration relationship between the EU and U.S. biodiesel prices, and the EU and U.S. diesel prices at a 1 percent significance level. The rest of diesel – biodiesel price series is found not to be cointegrated. The crude oil prices and biodiesel or diesel prices are not cointegrated either.

Results of the multivariate Johansen cointegration test indicate that the series under consideration are cointegrated of rank 3 in the case of gasoline and ethanol, and of rank 1 for the biodiesel and diesel prices. The cointegration analysis shows that fossil fuel and biofuel prices are interlinked. However, the cointegration analysis cannot predict the direction of causality between the price series. To identify the causality relationships we estimate the VAR model.

Variance Decomposition

Based on the VEC results, we perform variance decomposition of the price relationships to examine Hypotheses 1 and 2. The variance decomposition indicates how much the current and future values of a price can be explained by exogenous shocks to the other variables. According to the results reported in Table 5, in all three countries ethanol prices are most responsive to their own lagged values. However, effect decreases over time. The lagged ethanol price contributes to the variance of the own ethanol prices by more than 55 percent. The rest of price series (i.e., gasoline prices, non-lagged ethanol prices, and the crude oil price) participate individually with less than 45 percent in the variance of ethanol prices.

The U.S. ethanol price contributes to the variance of the European ethanol prices after 48 weeks by 4.1 percent. The relative variance in ethanol prices in Europe is then caused by the shocks to the Brazil ethanol prices (3.82 percent) and partially by the shocks to the gasoline market in the three countries (almost 5 percent all combined). The crude oil seems to have only a minor impact on the EU ethanol price (less than 0.5 percent).

On the other hand, the relative variance in the U.S ethanol prices is resistant to the shocks to the EU ethanol prices (0.07 percent after 48 weeks). The Brazilian ethanol price participates with 3.42 percent in the variance of the U.S. ethanol prices after 48 weeks. The relative variance in the U.S. ethanol prices caused by the shocks to Brazilian gasoline prices is even stronger, 16.34 percent. The variance decomposition results further support only a marginal impact of the U.S. gasoline prices (0.70 percent after 48 weeks) and of the EU gasoline price (less than 0.59 percent) on the U.S. ethanol prices. Finally, crude oil has a sizable impact on the U.S. ethanol price (14.15 percent).

The Brazilian ethanol price reacts particularly to crude oil price (14.79 percent), U.S. ethanol (12.86 percent), and U.S. gasoline (7.97 percent). Other prices show minor importance (less than 3.5 percent).

The results in Table 5 confirm that for ethanol hypothesis 1 tends to prevail relative to Hypothesis 2. Gasoline in other countries and the crude oil prices explain 4.02,[8] 24, and 31 percent of the ethanol price variation in the European Union, Brazil, and the United States, respectively (Hypothesis 1). On the other hand, the other countries' ethanol price contributes with 3.49,[9] 7.92, and 16.30 percent to the ethanol price variation in the United States, European Union, and Brazil, respectively (Hypothesis 2).

The U.S. and Brazilian policies appear to play an equal role in determining ethanol prices in other countries. The U.S. ethanol and gasoline contribute to the variance of the EU and Brazil ethanol prices by 5.04 [10] and 20.83 percent, respectively. Brazilian ethanol and gasoline prices contribute to the variance of the EU and U.S. ethanol prices by 6.48 percent and 19.76 percent, respectively. The EU plays a minor role in determining ethanol prices in other countries (less than 5 percent).

These results partly confirm the prediction of Kliauga, de Gorter, and Just (2008) that the United States is the price leader for ethanol. Contrary to their findings, we find that both the United States and Brazil play an equal role. However, the mechanism of price determination differs between the two countries. Both the United States and Brazil impact the EU ethanol through the ethanol price. However, the reciprocal effects are different. The United States determines Brazilian ethanol price mainly through the ethanol price (confirming Hypothesis 2), whereas Brazil affects the U.S. ethanol mainly through the gasoline price (confirming Hypothesis 1). The crude oil price is important in the United States and Brazil in affecting ethanol prices but not in the European Union.

With regards to biodiesel, akin to the ethanol, most of the variance in all biodiesel prices can be explained by its own innovations (more than 70 percent) (Table 6). The effect of the shocks to the EU biodiesel price on the current and future values of U.S. biodiesel price is much stronger than vice versa. The European biodiesel price contributes to the variance of the U.S. biodiesel prices after 48 weeks by 19.4 percent, while it is only 1.01 percent vice versa. The EU biodiesel is significantly affected by the EU diesel price (18.95 percent). Other prices play only a minor role in determining biodiesel prices in the European Union and the United States. Notably, an insignificant impact has been observed for the crude oil price on the biodiesel prices in both countries (less than 0.40 percent). These results confirm Hypothesis 2 and the prediction of de Gorter, Drabik, and Just (2010) that the European Union is the price leader in the world biodiesel market.

7. Concluding Remarks

This paper has empirically examined the theoretical findings of Kliauga, de Gorter, and Just (2008) and de Gorter, Drabik, and Just (2010). These papers show two patterns of the interaction

[8] 4.02% = 0.94 U.S. gasoline + 2.66 Brazil gasoline + 0.42 Crude oil.
[9] 3.49% = 0.07% EU ethanol + 3.42 Brazil ethanol
[10] 5.04% = 4.1% U.S. ethanol + 0.94 U.S. gasoline.

between biofuel policies and biofuel price determination. First, if the tax credit (exemption) is the driver of biofuel prices, then one would observe a price behavior where the crude oil price and the fossil fuel (gasoline or diesel) prices in the price leading country determine world biofuel prices. Second, if the biofuel mandate determines biofuel prices, then one would expect that biofuel (ethanol or biodiesel) price in the price leading country determines the world biofuel price.

In the case of the ethanol, the other countries' gasoline and crude oil prices explain between 4 and 31 percent of ethanol price variation. On the other hand, the other countries' ethanol price contributes to the ethanol price variation by 3.5 to 16 percent. We also find that the U.S. and Brazilian ethanol polices appear to be of equal importance in determining ethanol prices in other countries, thus partially confirming the prediction of Kliauga, de Gorter and Just (2008). However, the mechanism of price determination differs for these countries. The United States tends to cause the Brazilian ethanol predominantly through the mandate (confirming Hypothesis 2), whereas Brazil affects the U.S. ethanol mainly through the ethanol tax exemption policy (confirming the Hypothesis 1).

For biodiesel, our results demonstrate that the EU mandate impacts the world biodiesel price (Hypothesis 2) and confirm the prediction of de Gorter, Drabik, and Just (2010) that the EU is the price leader in the world biodiesel market.

References

Babcock, B.A. (2008). "Breaking the Link between Food and Biofuels." Briefing Paper 08-BP 53, July 2008, Center for Agricultural and Rural Development, Iowa State University

Balcombe, K., and Rapsomanikis, G. (2007) "Bayesian estimation of non-linear vector error correction models: the case of sugar-bioethanol-oil nexus in Brazil." Working paper, Department of Agricultural and Food Economics, University of Reading, Reading.

Ciaian, P., and Kancs, D. (2011). "Interdependencies in the Energy-Bioenergy-Food Price Systems: A Cointegration Analysis". *Resource and Energy Economics* 33: 326–348

de Gorter, H., and Just, D.R. (2009). "The Economics of a Blend Mandate for Biofuels." *American Journal of Agricultural Economics* Vol. 91: No. 3, August, pages 738-750.

__________. (2010). "The Social Costs and Benefits of Biofuels: The Intersection of Environmental, Energy and Agricultural Policy." *Applied Economic Perspectives and Policy*. Vol. 32. No. 1, Spring, pages 4-32.

de Gorter, H., Drabik, D., and Just, D.R. (2010). "The Economics of a Blender's Tax Credit versus a Tax Exemption: The Case of U.S. 'Splash & Dash' Biodiesel Exports to the European Union". A selected paper presented at Agricultural and Applied Economics Association 2010 Annual Meeting, July 25-27, 2010, Denver, Colorado.
http://ageconsearch.umn.edu/bitstream/61425/2/AAEA10348_deGorter%26Drabik%26Just.pdf

Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

Engle, Robert F., Granger, Clive W. J. (1987). "Co-integration and error correction: Representation, estimation and testing", *Econometrica*, 55(2), 251-276

Harris, R. (1995). "Using Cointegration Analysis in Econometric Modelling". London: Prentice Hall/Harvester Wheatsheaf.

Kliauga, E.M., de Gorter, H., and Just D.R. (2008). "Measuring the 'Subsidy' Component of Biofuel Tax Credits and Exemptions". Paper presented at the International Agricultural Trade Research Consortium meeting, Scottsdale Arizona, 7-9 December 2008 http://www.ilr1.uni-bonn.de/iatrc/IATRC_Scottsdale_degorter_just_kliauga.pdf

Reuters (2010). "U.S. to Use More Ethanol in 2011, But Smaller Market Share". Washington, Monday July 12, 2010. http://www.reuters.com/article/2010/07/12/us-usa-ethanol-target-idUSTRE66B4XR20100712

Xiaodong, D., and Hayes, D. (2009). "The impact of ethanol production on us and regional gasoline markets" *Energy Policy* 37 (2009), 3227–3234.

Zhang, Z., Lohr, L., Escalante, C., and Wetzstein, M. (2009). "Bioethanol, Maize, and Soybean Price Relations in a Volatile Vehicle-Fuels Market." *Energies*, 2009, 2, 320-339; ISSN 1996-1073

__________. (2010). "Food versus fuel: What do prices tell us?" *Energy Policy*, 38 (2010), 445–451

Appendix

To illustrate how biofuel price relationships are affected by a blend mandate, we perform a comparative static exercise for the impact of an exogenous fossil fuel (without loss of generality, we assume gasoline) price change on the biofuel price (ethanol), dP_E/dP_G, in the price leading country. The derivations are based on the model presented in Figure 1 in de Gorter and Just (2009).

The equilibrium conditions in the fuel market with an exogenous gasoline price and a binding blend mandate are given by:

$$\begin{gathered} P_F = \alpha\left(P_E - t_c\right) + \left(1-\alpha\right)P_G \\ S_E\left(P_E\right) = \alpha D_F\left(P_F\right) \end{gathered} \tag{A1}$$

where P_F, P_E, and P_G denote price of fuel, ethanol, and gasoline, respectively; t_c denotes a tax credit; α denotes a blend mandate (e.g., 10 percent), and S_E and D_F denotes ethanol supply and fuel demand functions, respectively.

Totally differentiating system (A1) yields:

$$\begin{gathered} dP_F = \alpha dP_E + \left(1-\alpha\right)dP_G \\ S_E' dP_E = \alpha D_F' dP_F \end{gathered} \tag{A2}$$

where D_F' and S_E' are the first derivatives of the fuel demand and ethanol supply functions , respectively, with respect to their arguments.

Solving system (A2) for dP_E/dP_G yields:

$$\frac{dP_E}{dP_G} = \frac{\alpha\left(1-\alpha\right)D_F'}{S_E' - \alpha^2 D_F'} < 0$$

Transformation to the elasticity form yields:

$$\frac{dP_E}{dP_G} = \frac{\left(1-\alpha\right)\eta_{DF}}{\eta_{SE}\frac{P_F}{P_E} - \alpha\eta_{DF}} < 0 \tag{A3}$$

where η_{DF} denotes demand elasticity of fuel and η_{SE} denotes supply elasticity of ethanol.
We extract needed elasticities from de Gorter and Just (2009) to calibrate the derivative (A3). The results are reported in Table 1.

Table 1. The Magnitude of dP_E/dP_G for the United States with a Binding Blend Mandate and an Exogenous Gasoline Price

Year	Ethanol Share of Fuel Consumption (α)	Ethanol Supply Elasticity (η_{SE})	Ethanol price (P_E)	Gasoline price (P_G)	Fuel price (P_F)	dP_E/dP_G (for η_{DF} = -0.10)	dP_E/dP_G (for η_{DF} = -0.26)	dP_E/dP_G (for η_{DF} = -0.40)
2001-02	0.015	13.60	1.59	0.95	0.96	-0.012	-0.031	-0.048
2002-03	0.021	9.30	1.13	0.76	0.77	-0.015	-0.040	-0.062
2003-04	0.025	8.60	1.25	0.96	0.97	-0.015	-0.038	-0.059
2004-05	0.029	8.60	1.60	1.13	1.14	-0.016	-0.041	-0.063
2005-06	0.038	6.90	1.62	1.49	1.49	-0.015	-0.039	-0.060
2006-07	0.048	5.10	2.61	1.99	2.02	-0.024	-0.063	-0.096
2008-09	0.070	3.10	2.40	3.00	2.96	-0.024	-0.063	-0.097

Source: calculated

Table 2. Correlation between Ethanol, Gasoline, and Crude Oil Prices

Variable	EU ethanol	U.S. ethanol	Brazilian ethanol	EU gasoline	U.S. gasoline	Brazilian gasoline	Crude oil
EU ethanol	1.000						
U.S. ethanol	0.649	1.000					
Brazilian ethanol	0.717	0.614	1.000				
EU gasoline	0.857	0.736	0.757	1.000			
U.S. gasoline	0.826	0.762	0.723	0.976	1.000		
Brazilian gasoline	0.919	0.673	0.860	0.919	0.880	1.000	
Crude oil	0.871	0.696	0.760	0.975	0.962	0.915	1.000

Source: calculated

Table 3. Correlation between Biodiesel, Diesel, and Crude Oil Prices

Variable	EU diesel	U.S. diesel	EU biodiesel	U.S. biodiesel	Crude oil
EU diesel	1.000				
U.S. diesel	0.969	1.000			
EU biodiesel	0.860	0.795	1.000		
U.S. biodiesel	0.778	0.735	0.897	1.000	
Crude oil	0.082	0.026	0.365	0.355	1.000

Source: calculated

Table 4. Cointegration Results

	Trace test		λ_{max} test	
	r = 0	**r = 1**	**r = 0**	**r = 1**
EU ethanol – Brazilian ethanol	16.03 ***	3.03	13.00 ***	3.03
EU ethanol – U.S. ethanol	20.95	4.78 **	16.17	4.78 **
EU ethanol – EU gasoline	20.04	5.87 **	14.17	5.87 *
EU ethanol – U.S. gasoline	21.93	5.48 **	16.45	5.48 **
EU ethanol - Brazilian gasoline	15.77 ***	4.33	11.44 ***	4.33
U.S. ethanol – Brazilian ethanol	20.43	3.97 **	16.47	3.97 **
U.S. ethanol - Brazilian gasoline	24.03	4.49 **	19.54	4.49 **
U.S. ethanol - EU gasoline	29.18	8.42 ***	20.76	8.42 ***
U.S. ethanol - U.S. gasoline	29.69	7.55 ***	22.14	7.55 ***
U.S. gasoline - EU gasoline	47.86	8.63 ***	39.24	8.63 ***
Brazilian ethanol – Brazilian gasoline	23.07	4.13 **	18.94	4.13 **
Brazilian ethanol - U.S. gasoline	20.79	3.74 **	17.05	3.74 **
Brazilian ethanol - EU gasoline	20.96	5.64 **	15.33	5.64 *
Brazilian gasoline – U.S. gasoline	29.86	4.43 ***	25.43	4.43 ***
Brazilian gasoline - EU gasoline	29.99	5.31 ***	24.67	5.31 ***
Crude oil - EU ethanol	18.72 ***	4.44	14.28 ***	4.44
Crude oil - U.S. ethanol	24.18	6.36 **	17.82	6.36 **
Crude oil - Brazilian ethanol	20.17	4.58 **	15.60	4.58 *
Crude oil - EU gasoline	34.36	5.34 ***	29.02	5.34 ***
Crude oil - U.S. Gasoline	30.08	4.74 ***	30.08	4.74 ***
Crude oil Brazilian gasoline	28.69	4.64 ***	24.05	4.64 ***
EU biodiesel – EU diesel	12.29 ***	3.48	8.81 ***	3.48
EU biodiesel – U.S. biodiesel	32.53	3.60 ***	28.93	3.60 ***
EU biodiesel – U.S. diesel	12.81 ***	4.42	8.39 ***	4.42
EU diesel – U.S. biodiesel	17.46 ***	3.07	14.39 ***	3.07
U.S. diesel - EU diesel	27.85	4.10 ***	23.75	4.10 ***
U.S. biodiesel – U.S. diesel	14.29 ***	2.57	11.72 ***	2.57
Crude oil - EU diesel	7.70 ***	2.84	4.86 ***	2.84
Crude oil - EU biodiesel	10.14 ***	1.89	8.25 ***	1.89
Crude oil - U.S. diesel	11.71 ***	3.88	7.83 ***	3.88
Crude oil - U.S. biodiesel	12.74 ***	2.13	10.61 ***	2.13

Source: calculated

Note: * significant at a 10% level, ** significant at a 5% level, *** significant at a 1% level

Table 5. Variance Decomposition Results for Ethanol, Gasoline, and Crude Oil Prices

Number of weeks	Relative variance in…	Percentage of forecasted variance explained by innovations in…						
		Δ EU ethanol	Δ U.S. ethanol	Δ Brazilian ethanol	Δ EU gasoline	Δ U.S. gasoline	Δ Brazilian gasoline	Δ Crude oil
1	Δ EU ethanol	95.86	2.09	2.05	0.00	0.00	0.00	0.00
4		94.03	2.16	3.22	0.05	0.42	0.06	0.07
12		90.04	3.75	4.48	0.29	0.32	0.84	0.28
24		87.84	4.47	3.97	0.69	0.80	1.73	0.50
48		87.05	4.10	3.82	1.01	0.94	2.66	0.42
1	Δ U.S. ethanol	0.00	98.39	1.61	0.00	0.00	0.00	0.00
4		0.33	98.24	0.91	0.09	0.28	0.10	0.04
12		0.15	96.18	0.97	0.05	0.22	1.28	1.14
24		0.09	80.71	1.95	0.43	0.19	9.78	6.83
48		0.07	64.74	3.42	0.59	0.70	16.34	14.15
1	Δ Brazilian ethanol	0.00	0.00	100.00	0.00	0.00	0.00	0.00
4		1.78	0.78	95.44	0.60	0.03	0.57	0.79
12		3.71	9.18	72.91	1.89	1.88	0.29	10.12
24		3.52	13.24	59.85	1.60	6.20	1.09	14.51
48		3.44	12.86	57.22	1.24	7.97	2.48	14.79

Source: calculated

Note: Δ - change

Table 6. Variance Decomposition for Biodiesel, Diesel, and Crude Oil Prices

Number of weeks	Relative variance in…	Percentage of forecasted variance explained by innovations in…				
		Δ EU biodiesel	Δ U.S. biodiesel	Δ EU diesel	Δ U.S. diesel	Δ Crude oil
1	Δ EU biodiesel	99.13	0.87	0.00	0.00	0.00
4		97.28	1.13	0.09	1.03	0.46
12		91.26	1.08	6.57	0.95	0.15
24		83.81	1.06	14.48	0.55	0.10
48		79.62	1.01	18.95	0.34	0.08
1	Δ U.S.	0.00	100.00	0.00	0.00	0.00
4		5.22	92.37	0.28	1.88	0.25
12		14.70	79.98	0.34	4.60	0.39
24		17.93	75.40	1.48	4.82	0.37
48		19.40	72.97	2.63	4.65	0.35

Source: calculated

Note: Δ - change