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PRICE TRANSMISSION AND POLICIES IN BIOFUELS-RELATED GLOBAL NETWORKS

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Price Transmission and Policies in Biofuels-Related Global Networks

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Abstract:

This article investigates the connections between the prices of biofuels and many traded commodities and other relevant assets in Europe, USA and Brazil. The analysis uses a comprehensive dataset covering price data for 38 traded titles over the period 2003-2020. We utilize the minimum spanning tree approach to identify price connections in a complex trading system. Our analysis of mutual price connections discovers the major defining features of world leading biofuels markets during the period since the ground-breaking policy initiatives of the 2003 EU Transport Fuel Directive and Energy Taxation Directive. We provide characteristics of main bioethanol and biodiesel markets with respect to government policies and technical and local features of the production and consumption of particular biofuels. Despite a relatively long and dynamically evolving history of biofuels, we find that the biofuels systems in USA, Brazil and Europe do not converge towards the same pattern of relations among fossil fuels, biofuels, agricultural commodities and financial assets.

JEL: C38, Q16, Q42
Keywords: ethanol; biodiesel; minimum spanning tree; energy and agricultural policies

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1 Introduction

As identified in the early contributions of Tyner and Taheripour (2008) and Tyner (2010), agricultural and energy markets had not been closely correlated before the advent of biofuels. Consequently, the energy and agricultural policies were being developed, implemented, and evaluated apart. All this has changed during the last 20 years. In this paper, we investigate the biofuels policies induced interaction of energy and food prices over the period starting at the introduction of the EU 2003 Transport Fuel Directive and Energy Taxation Directive and covering the market evolution up to the global onset of the COVID-19 crisis in early 2020.

We briefly introduce the major biofuels related policies in all three globally decisive regions of the biofuels development - USA, Brazil, and Europe (EU). Subsequently, we continue with the empirical analysis of a global system of biofuels-induced price transmission among main energy and agricultural commodities and potentially related financial assets. Our results show a dynamic evolution of the biofuels-related price co-movements with different levels of price integration during the four main sub-periods identified in our analysis. Despite a relatively long and dynamically evolving history of biofuels, we find that the biofuels systems in USA, Brazil and Europe do not converge towards the same pattern of relations among fossil fuels, biofuels, agricultural commodities and financial assets.

As outlined in the comprehensive book on biofuels policies by de Gorter et al. (2015) as well as in the influential article of Zilberman et al. (2013), the literature on fuel-food economic policies and resulting price linkages uses three main modelling approaches – theoretical models of channels leading to prices connectedness (Boutesteijn et al., 2017, Ciain and Kancs, 2011a, b, Drabik et al., 2014, 2015, 2016, Rajcaniova et al., 2013, 2014), partial and general equilibrium models simulating the market interdependencies (Beckman et al., 2012, Zhao et al., 2021, Taheripour et al., 2021, Taheripour and Tyner, 2020, Campbell et al., 2018), and time series analyses, which is a method used in this article.

Mutual co-movement of time series of prices of biofuels and related assets is a subject of a large literature which was reviewed in detail already by Serra (2013) and Serra and Zilberman (2013) and more recently by Janda and Kristoufek (2019).

There is a large number of different time series techniques which have already been used for investigation of biofuels-related price transmission analyses. Some of them are very standard mainstream time series econometrics techniques like VECM (Rajcaniova and Pokrivcak, 2011; Filip et al., 2019, Ciaian and Kancs 2011a,b, Zhang et al., 2010), VAR or SVAR (Capitani et al., 2018, Kristoufek et al., 2014, Dalheimer et al., 2021), GARCH type models (Abdelradi and Serra, 2015, Serra et al., 2011), ARDL (Dutta 2018) or more general Granger causality approaches (Bastianin et al., 2016). However, less common techniques like copulas (Reboredo, 2012, Tiwari et al, 2021), wavelets (Pal and Mitra, 2017, Kristoufek et al., 2016, Vacha et al., 2013, Filip et al., 2016) or frequency-dependent spillovers (Pal and Mitra, 2020) are used as well.

In this article, we utilize the minimum spanning tree technique which was introduced to the biofuels-related research by Kristoufek et al. (2012) and Lautier and Raynaud (2012). In large systems of variables, it is especially difficult to identify connections above the standard pairwise perspective as the testing statistics or estimated parameters are by definition given for a specific one-to-one relationship. The minimum spanning trees are built on such pairwise connections as well but they provide a more complex picture of the connections as the co-movement dynamics is represented as a connected graph. Such visualization helps to better understand the interconnections in the whole system together rather than studying the connections separately and thus it is making the interpretation much more straightforward.

2 Biofuels policies

2.1 European Union

The first attempt to promote the use of biofuels in the EU was the Transport Fuels Directive in 2003 (Directive 2003/30/EC). The main aim of the directive was to establish indicative targets that would set what amount of the total amount of the transportation fuel that will be consumed in the EU should be represented by biofuels. The numbers were set at 2% by 2005 and 5.75% by 2010. Subsequently, it was required from Member States to report their achievements and their fulfilment of the target annually but the targets were not met as in the year 2006, since the number only reached 1.06%, and in the year 2010, it was only 3.9% (Flach et al., 2019).

Second important EU legislation that was passed in 2003 was the Energy Taxation Directive (Council Directive 2003/96/EC) that included tax reductions for biofuels and its purpose was to make biofuels cost lower to make them competitive with the traditional fuels. The implementation of this directive varied across the Member States. However, all of the Member States that managed to increase their use of biofuels had put certain tax exemptions into place, which subsequently helped biofuels to be more cost efficient and therefore compete with traditional fossil fuels (Janda et al., 2012). Large fiscal cost of these tax exemptions meant that later on, the EU governments chose the path of making the use of biofuels obligatory to a certain degree rather than providing tax exemptions.

The directives that created the basis for legislative framework for biofuels in EU were the Energy and Climate Change Package (CCP) and the Fuel Quality Directive (2009/30/EC) which was amended in 2009. The CCP included also the Renewable Energy Directive (RED) which came with the 20/20/20 target, which also stated the obligation that 20% of all the energy in the EU should be made from renewable sources, along with the target of 10% for the energy that is consumed in transportation until the year 2020. Apart from the usage of biofuels, the directive was also focused on the reduction of greenhouse gases (GHG). RED Article 17 also included the sustainability criteria that define the minimum level of GHG emissions savings, appropriate land use, etc. for a biofuel to be considered sustainable. A problem arose once the EU policymakers were forced to realize that some of the measures that were taken in order to better the environment are actually probably contributing more to the detriment of the planet ecosystem.

Consequently, the European Commission decided to introduce the Indirect Land Use Change (2015/1513/EC) legislation in 2015, which finally took into account the GHG emissions that are being released into atmosphere as a result of the excessive land use by the producers of biofuels (Zilberman, 2017) . The directive put a limit of 5% on the number of first-generation food-based biofuels and set multipliers that will apply for advanced biofuels. The positive aspect is that the EU is likely to meet its 20% and the 10% binding target in 2020 as it achieved a 19.7% share of renewable energy with the transport sector achieving 8.9% in 2019.

Following that is the 2030 climate and energy framework that simply increases the targets that it previously set in the 2020 framework. Continuing the legislative path is the successor of the Renewable Energy Directive, a revised “RED II” (Directive EU 2018/2001). The main goal of RED II is to reach a new target of 32% in the overall use of renewable energy and 14% in the transport sector, while also keeping the different national targets for each Member State. It also includes a very ambitious target of 3.5% by 2030 for the use of advanced biofuels which are not food-based and are not derived from fats or oils. Along with the new targets, RED II introduced new GHG emission thresholds for biofuels in order for them to be counted into the 14% target.

What lies ahead of the EU now is the issue of fulfilling the targets and making the energy sources used as renewable as possible. The future challenge will also be the completion of the Common Agricultural Policy 2021-2027. The legislative proposal, which was introduced in 2018, showed that in future, the member states will have the possibility to create their own strategic plans to cover the time period 2021-2027 in order to meet the targets set.

More detailed description of a history of EU biofuels policies is provided by Drabik and Venus (2019).

2.2 USA

The first legislative piece that established the USA biofuels legislative position was the Energy Tax Act in 1978 which introduced a tax exemption for ethanol and ethanol-blended gasoline (Gotter, Drabik, and Just, 2015). An immensely important piece of legislation that followed was the Energy Policy Act that came into effect in 2005 (Rajagopal and Zilberman, 2007). It further increased the tax incentives for biofuels and importantly, it created a foundation for the Renewable Fuels Standard, a program that still defines the targets for biofuels use, which then established a requirement for biofuels consumption to represent 4 billion gallons in 2006 and was further increased to 7.5 billion in the year 2012 . The bill also provided substantial funding for research linked to biofuels and biomass.

The Renewable Fuels Standard was further amended in 2007 by the creation of the Energy Independence and Security Act (EISA) which mainly focused on the expansion of the biofuel blending mandates along with the requirements for the fuels that are being used in transportation to contain a minimum of 36 billion gallons of renewable fuels by 2020. The new act also encouraged research and development of advanced, next generation biofuels, which created a space to put a new target in place. This time it required 16.9 billion gallons of cellulosic biofuels and 21 billion gallons total of advanced biofuels to be used by 2020.

The Food, Conservation, and Energy Act of 2008, which is sometimes referred to as the „Farm Bill", was the key to creating many new energy programs such as the Biorefinery Assistance Program, the Biobased Marketing Program and the Biomass Crop Assistance Program, which were further expanded by The Agricultural Act of 2014.

As far as the administration of the previously mentioned RFS program goes, it is all done by The U.S. Environmental Protection Agency (EPA). Their main focus is to create the volume requirements for the subcategories into which biofuels are being divided, and they also establish annual minimum quantities for biofuels. EPA also tracks compliance thanks to the creation of the Renewable Identification Number (RIN) system, which assigns a RIN to each gallon of renewable fuel (Schnepf and Yacobucci, 2012). When we look at some future predictions, the US is still maintaining the trend in biofuels targets. A very significant announcement that came in 2020 is the one of the U.S. Department of Agriculture which informed that biofuels blend rates are set to 15% for transport fuels in the US in 2030 and 30% of transport fuels by the year 2050 (U.S Department of Agriculture, 2020).

A more detailed critical analysis of the USA biofuels policies is provided by Hochman and Zilberman (2018) and Khana et al. (2021).

2.3 Brazil

Similar to the USA one of the first reasons why Brazil started to look for alternative fuels was the oil crisis in 1973, which again, in a way, helped to create the globally first important legislation concerning biofuels, The National Alcohol Program (PROÀLCOOL) in 1975, the program that promoted the use of bioethanol as an automobile fuel instead of the traditional fossil fuel (Timilsina and Zilberman, 2014). This was quite obvious, since sugar cane was an accessible, low-cost material to produce ethanol fuel from, while the second most common feedstock is corn. Brazilian government then also came to conclusion that the best way to promote the use of biofuels, namely bioethanol, will be to create a mandate for the minimum blend in gasoline, which reached 22% in 1992. This program was terminated in the 1990s, but certain regulations and tax incentives were still kept in place. Furthermore, other policies were created, namely the National Policy on Climate Change in 2009 and the Law on the Protection of Native Forests in 2012 to keep up with the plans to protect the environment and mitigate climate change.

Along with bioethanol, the Brazilian government also introduced the National Program on Biodiesel Production and Usage in 2005, which required that from 2008 until 2012, 2% of the consumption of petrol-based diesel are to be substituted by oilseed and animal-fat derived biodiesel (Barros, 2020). The target was later increased to 5% of biodiesel from 2013. The mandate has later been set to 10% since March 2018. Further, the ANP (Natural Gas and Biofuels National Agency) approved 1% annual increase of the blend of biodiesel. Still, biodiesel production is highly regulated by the government.

In 2017, an import tariff came into power, with the allowed amount of 600 million litres of ethanol that can be imported, while any volume above that will be a subject to the 20 % Common External Tariff under the Mercosur agreement. Thanks to this agreement, Brazil also expects a very sharp increase in the number of sugar and ethanol that will be exported into the European Union, which would lead to nearly triple the export revenues for Brazil, compared to 2018 (Barros, 2020).

A very important piece of legislation that came into force in 2020 is the Renovabio Program, which confirms Brazil’s commitment to the Paris Agreement. Its main focus is to decrease the carbon intensity in the form of GHG emissions by 37% by 2025 and further to 43% by 2030. It also certifies biofuels by their efficiency in reducing GHG emissions and introduces decarbonization credits (Barros, 2020).

Further discussion of Brazil biofuels policies is provided by Khanna et al. (2016) and by Denny (2020).

3 Methodology

We investigate the co-movement of biofuels-related prices through the minimum spanning trees (MST). The starting point of MST analysis are the Pearson pairwise correlation coefficients ρ_{ij} which were used in a seminal agenda setting articles Tyner and Taheripour (2008) and Tyner (2010) to illustrate the paradigm of integrated energy and agricultural markets. The MSTs reconstruct the correlation structure from the correlation matrix through distances and the outcoming tree-like structure than represents the most important connection in a system of variables or a network. In order to translate the correlations ρ_{ij} into distances, we follow Mantegna (1999) by transforming the correlation coefficients ρ_{ij} so that they represent an appropriate measure of distance by using the formula:

$$d_{ij} = \sqrt{2(1 - \rho_{ij})}.$$

Matrix $\mathbb{D}$ composed of distances d_{ij} meets all the criteria of the Euclid's metric:

$$(1)\ Identity : d_{ij} = 0 \Leftrightarrow i = j, \forall i, j \in N$$

$$(2)\ Symmetry : d_{ij} = d_{ji}, \forall i, j \in N$$

$$(3)\ Triangle\ inequality : d_{ij} \leq d_{ik} + d_{kj}, \forall i, j \in N$$

The values of the coefficients d_{ij} are strictly positive, varying between 0 and 2. For d_{ij} = 0, we have perfect positive correlation, d_{ij} = √2 means no correlation and d_{ij} = 2 represents perfect negative correlation. The transformation provides following matrix $\mathbb{D}$:

$$\mathbb{D} = \begin{pmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{pmatrix} = \begin{pmatrix} 0 & d_{12} & \dots & d_{1n} \\ d_{21} & 0 & \dots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \dots & 0 \end{pmatrix}$$

There are several algorithms that can be used to find the MST. In our paper, we use the Kruskal's algorithm (Kruskal, 1956). The basic way that this algorithm works can be described as that it starts with all of the possible $\frac{n(n-1)}{2}$ connections (where n is the number of variables) and subsequently, it systematically eliminates the weakest links, or in our case the largest distances found between the nodes, until it is still possible to connect all nodes with their links. This elimination will result in a significantly lower number of linkages that are now decreased to only $n-1$ value for the minimum spanning tree. Such a simplified graph is much more legible and easier to visually comprehend than the initial matrix of all pairwise correlation coefficients. All of the computation that are necessary for this part were processed in R software, while the visualization of MST was done through the igraph package.

The problem that we would likely have to face when it comes to using the minimum spanning trees analysis lies in the possible instability of the links between each input. In order to check the stability of the links and find out whether they are actually relevant or appear in the structure rather randomly, we use the bootstrapping technique, which was introduced in Tumminello et al. (2007). To do so, we take the already created MST and we construct a bootstrapped version of the times series that the previous MST was created from and based on. We will then keep the whole dataset as it is, however, now we will allow for the dataset to get randomly reorganized and we will also allow repetitions, which can simply mean that some links will be completely omitted while some can appear multiple times. This will create a new MST structure, whose links are then recorded, while this process is repeated 1000 times overall. The procedure will finally leave us with a precise number of how many times out of one thousand a certain link appeared in our MST construction. All of these values are then marked for each edge as $b_{ij} \in [0; 1]$, which is the ratio of the actual number of appearances in the MST to the total number of realized bootstraps. We consider a value greater than 0.5 as a fairly stable link.

4 Data

Our dataset contains 38 price time series of different commodities and assets that are in some way possibly connected to the prices of biofuels. A detailed description of the data is provided in Schererova (2020). For our analysis we transform our raw data into logarithmic returns following this formula:

$$r_t = log\ (P_t) - log\ (P_{t-1}) = log\frac{Pt}{Pt-1}.$$

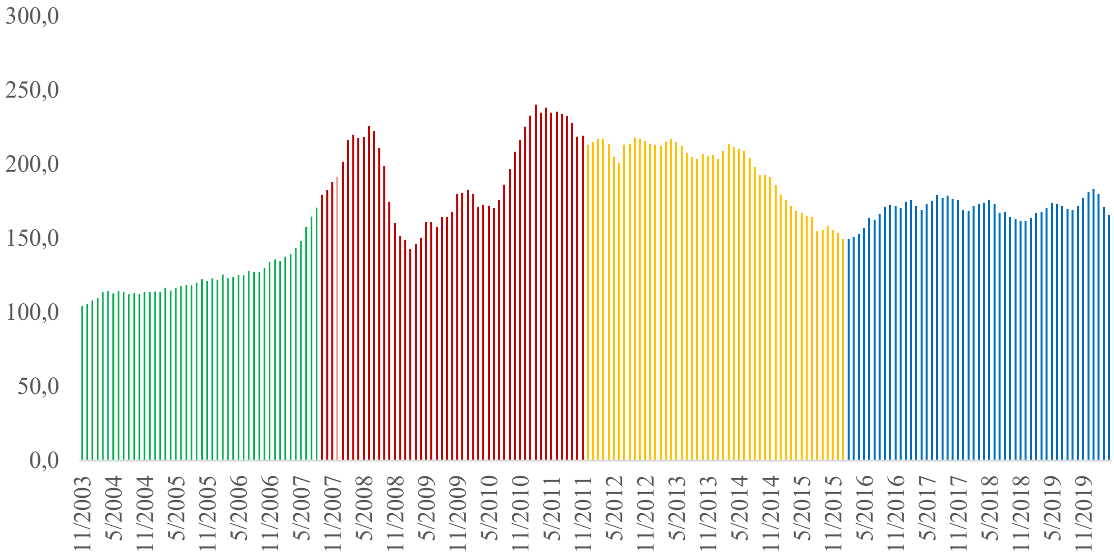
For the construction of MSTs, we need to get a correlation matrix first which means that such correlations need to be defined. The studied series thus must not contain unit roots. Combination of the Augmented Dickey-Fuller test and the Kwiatkowski-Phillips-Schmidt-Shin test (results are listed in the Appendix) allows the log-return series to be utilized for the analysis.

Each of our time series is a collection of weekly prices that are from the period of 21st of November 2003 until 24th April 2020. As far as the day of the collection is concerned, we always looked for Friday data, only in times when Friday data was not available the data from the closest previous day were used. The time span that our dataset covers is approximately 18 years which leads to 858 weekly observations.

We divided the whole dataset into smaller parts according to the price fluctuations that can be noticed after closer inspection. As a lead, we use the Food Price Index (FPI) which is being published by Food and Agricultural Organization of the United Nations (FAO). The FPI measurement is done in its own scaled points and the years 2002 – 2004 represent 100, the base period. As we closely inspect the FPI (Figure 1), we can clearly observe two very high price spikes, in the years 2008 and 2011, reaching their maximum in the winter of 2011. The prices then decrease gradually until year 2015, after which the prices remained relatively stable. FPI helped us to divide the whole period into certain parts according to the changes that we could observe, which implies that we ended up with four periods which divided our dataset into four groups. While the first period is representing the calmer years, the years before the food crises, the second period includes two very significant price spikes. The third period is the period of slow decline in prices, while the last, fourth period exhibits quite stable times with a small and slow rise in prices. Specifically, the periods are split in the following way:

- **Period I: 22.11.2003 – 31.08.2007** (198 observations)
- **Period II: 07.09.2007 – 28.10.2011** (217 observations)
- **Period III: 4.11.2011 – 25.12.2015** (217 observations)
- **Period IV: 1.1.2016 – 24.04.2020** (226 observations)

Figure 1: FAO Food Price Index



Source: Authors' computations

Let us now focus on the groups of variables in our dataset:

Biofuels

The USA ethanol production is mostly connected to the New York Harbor Price Ethanol Index coded as ETHNNYPR Index from the Bloomberg Datastream, which we use. The Brazilian ethanol production is represented by the data on Anhydrous ethanol index from Centro de Avancados em Economica Aplicada (CEPEA). As those can be seen as two countries which represent two of the main world producers of ethanol, these are the only data that we used for ethanol. When it comes to biodiesel production, we also have to divide that into two separate datasets, which both follow the prices of biodiesel that is produced from rapeseed, differentiating only between the European and US market. Biofuels will be depicted in orange color in our MSTs.

Bioethanol feedstock

When it comes to bioethanol feedstock, there are different crops that can be used in the production of ethanol, but they must comply with one condition overall and that is that their content must be very high in sugar. Still, most of ethanol is either produced from corn (in the case of the USA) or from sugar cane (in the case of Brazil). In the dataset, we use the International Exchange prices of raw centrifugal sugar cane, along with sugar beets that are sometimes also used in the production of ethanol and are included in the form of LIFFE Sugar beets price index. When it comes to Brazil, we once again use the CEPEA Crystal sugar price index. As far as corn is concerned, it is incorporated into the dataset in the form of CBOT Corn composite. Even though that it is seen as the crop with smaller usage in the production of ethanol, we also decided to include the prices of wheat. The bioethanol feedstock will be depicted in yellow color in our MSTs.

Biodiesel feedstock

As far as biodiesel is concerned, it comes predominantly from processing rape seed oil that is mainly used in the EU and soybean oil which is seen as the main feedstock when it comes to the US biodiesel. Other important biodiesel feedstocks are palm oil and sunflower oil, for which we failed to find an adequate data, therefore we will be using sunflower seeds instead. Biodiesel feedstocks are depicted in red.

Food

Some previous literature directs towards using not only the feedstock that is directly connected to the production of biofuels, but to broaden the spectrum of data when it comes to food commodities as it may be beneficial in order to find out possible linkages that could appear between biofuels and the prices of food. To do so, we will be using the prices of rice (CBOT), cocoa, coffee, and orange juice (ICE-US), which are not used for biofuel production, but could potentially further show the relationship between "food and fuel". We also included USA cotton and feeder cattle. All of these will be represented in green.

Fossil fuels

Since biofuels are the main object of our focus, it is rather natural that we need to observe their closest substitutes and those are represented by fossil fuels. Because of that, we tried to create a sufficient dataset with representatives of all types of fossil fuels. Starting with crude oil, we included Brent Crude oil along with West Texas Intermediate (WTI). When it comes to gasoline and diesel, they were sourced from U.S. Energy Information Administration as far as USA prices are concerned, Agência Nacional do Petróleo (ANP) when it comes to Brazil, and for Europe, we used the price of German diesel and gasoline from Thomson Reuters DataStream, where the original unit was kilolitres, which we changed into gallons according to the current conversion rate (approx. 264,17205124156 gallons for 1 kilolitre)[1] . For the dataset to be complete, we consider also a substitute of gasoline and diesel. To do that, we will work with heating oil and natural gas (Henry Hub Natural), both of which are traded at NYMEX. The fossil fuels are shown in the dark red color.

Stock Indices

As Serra and Zilberman (2013) suggest, along with all the assets that are somehow connected to biofuels, the dataset should also include data of external factors that could possibly influence the price linkages that are being analyzed. These could include various financial instruments, interest rates, stock indices and also the legislation in different countries along with regulations. Similar recommendation can be found in Kristoufek, Janda, and Zilberman (2012). To represent these external factors, the use of national stock indices can be used as a substitute for GDP, since it is an up-to-date measure to reflect what is happening at a certain moment on the chosen market. The use of stock index will also make it possible for us to use such

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[1] www.convertunits.com

data instead of GDP, since the weekly frequency is more suitable for our dataset. When it comes to the choice of indices, it was clear that we need to cover the key biofuels market – the USA, Brazil and Europe. Therefore, the indices that we will use are the American Dow Jones Industrial Average (DOW JONES) and Standard and Poor's 500 (S&P 500) indices, along with the European British Financial Times Stock Exchange 100 (FTSE 100) and German Deutsche Boerse DAX (DAX) indices and finally Brazilian *Bolsa de Valores do Estado de Sao Paul* (Bovespa) index. Indices will be depicted in grey color.

Interest rates

Taking previous recommendations into account, we also include the two most important global interest rates. Firstly, the USA Federal funds rate, which is the basic interest rate of the USA central bank. And secondly, we will be using daily interbank rate that is used for short-term interest rates, 3-month London Inter-bank Offered Rate (LIBOR). Both of these are obtained from Federal Reserve Bank of St. Louis[2] and they will be shown in pink color.

Exchange rates

Since we are analysing mostly commodities on the three biggest biofuels markets – Europe, USA and Brazil, we will use the exchange rates of USD/EUR and USD/BRL. Even though most of the prices of the assets that we deal with are in dollars, they are still being consumed locally and paid for with local currency, therefore we need to take into account the exchange rates in order to see the relationship between different markets. Both of these rates were acquired from Thomson Reuters Eikon and they are shown in blue color.

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[2] www.fred.stlouisfed.or

5 MST Analysis

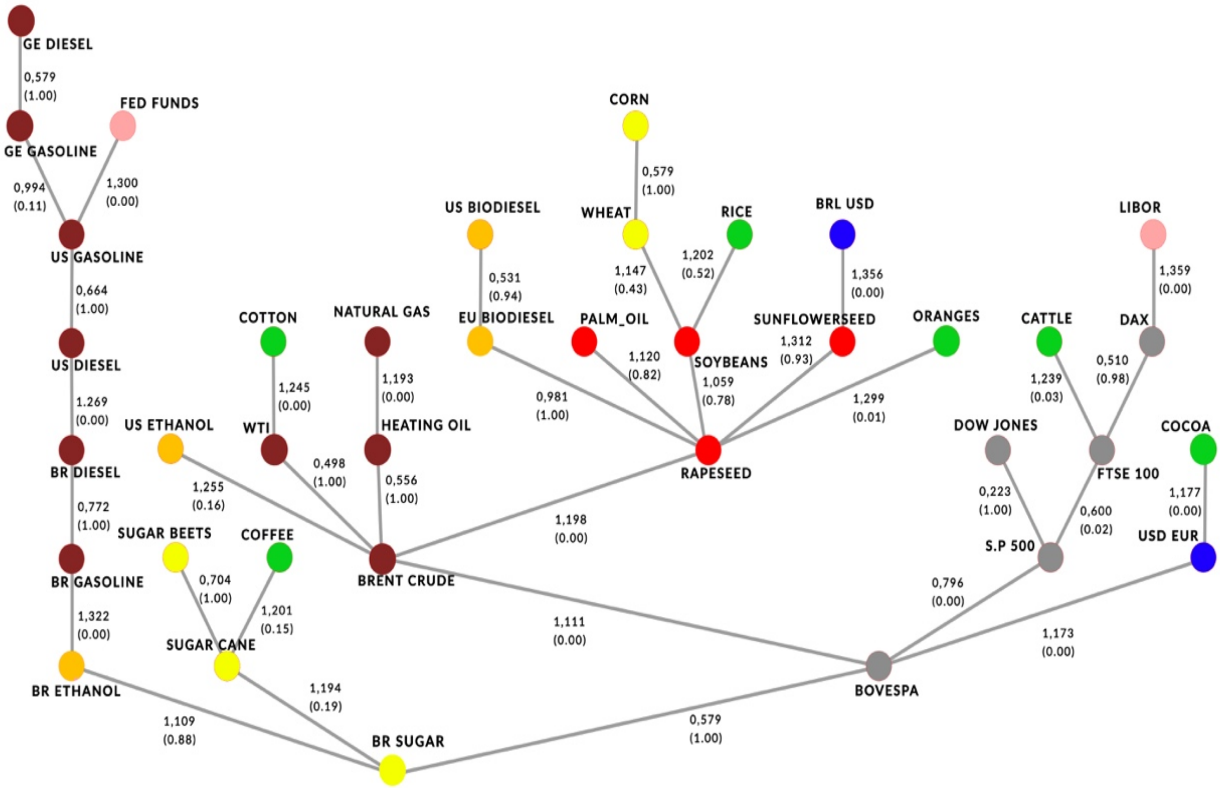
5.1 Entire time period – 11/2003 – 4/2020

In the MST graphs, each edge that connects two assets has two numerical values depicted next to it. Firstly, the one without brackets represents the distance d_{ij} that denotes the strength of the correlation between the two assets. In this case, we see that all distances d_{ij} are varying from 0 to $\sqrt{2}$, where smaller numbers represent stronger relationship between the two (as it is a distance). The second important number that is depicted in our MST graphs, the one in the brackets, represents the value created by the bootstrap, b_{ij}, representing the ratio between the number of times that this particular pair-wise link appeared in the bootstrapped MST from the thousand repetitions. We will use the value of $b_{ij} = 0{,}5$ as a value from which we consider certain link as a stable one.

Looking at the MST of an entire period in Figure 2, firstly we describe how the previously defined methodology works. The first pair that is created with the lowest number, representing the closest link or the strongest relationship is the Dow Jones and SP 500, with the distance of 0.223, which will create a pair in every single one of our MSTs. This is quite intuitive, considering that they are both from the USA stock market. We can also say with confidence that all financial indices are interconnected to some extent and they will form a cluster in every period of our analysis. In the second step of construction of this MST, Brent crude oil and WTI are connected with the distance of 0.498 along with a strong connection of Brent crude oil with heating oil as well (0.556). We also have to stress that all of the above-mentioned links along with other important relationships that were formed are not random, and their bootstrap value that is in the brackets is usually equal to 1 or is very close to 1, meaning that these connections appeared in all or almost all of the 1000 bootstrapped cases. This can really assure us that these relationships are stable throughout the whole period and will appear nearly in every MST that we analyze. Another important connection is the one of the two indices FTSE 100 and DAX, both coming from the European financial markets. The algorithm will then proceed with the elimination of the weakest connections, leaving us with previously mentioned $n - 1$

connections (edges), which in our case represent 37 edges that can be observed in the MST structure. What will result from such elimination are various clusters, that are formed into groups – clusters based on certain similarities that the assets possess, as further described by Sieczka and Hołyst (2009). The commodities that end up in a cluster together either belong to the same sector or are interconnected in a similar way.

Figure 2: Minimum Spanning Tree – Entire period 2003-2020



Source: Authors’ computations

We are able to distinguish between main 5 clusters. The first one consists of the stock indices that will be further present in some form in all of the MSTs presented here. From there, we can observe the connection provided by Brazilian stock market index Bovespa, which is not very meaningful on its own, based on the bootstrapped b_{ij} value, but provides a connection to other clusters.

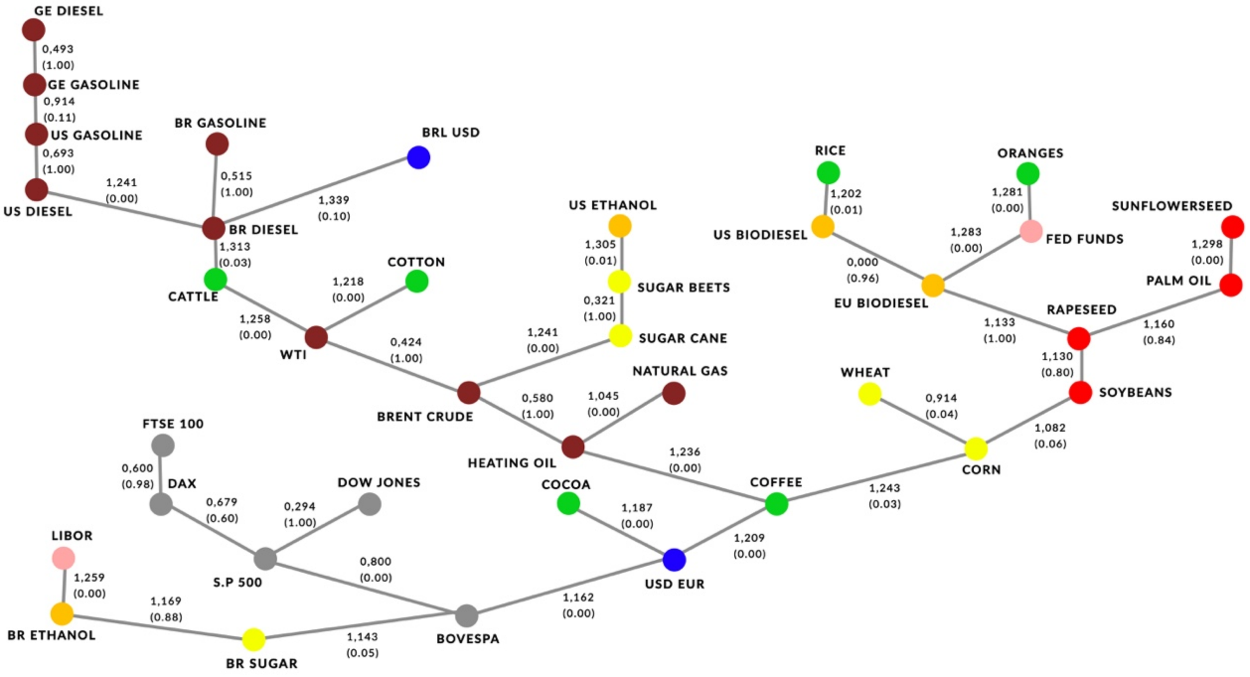
While the color code for related commodities and assets in general clearly indicates that similar assets are usually clustered together, a clear exception are interest rates and agricultural commodities not serving as biofuels feedstock, which are spread all over the MST with d_{ij} close to $\sqrt{2}$, indicating very low correlation and with b_{ij} close to 0, indicating low stability of the particular connection. We follow with MSTs for specific time periods set up earlier showing more regularities emerging and corresponding to particular stages of biofuels development.

5.2 Period I – 11/2003 – 8/2007

This is a period of an initial stage of biofuels boom with biofuels supporting policies being promoted all over the globe. During this period, there was a significant increase of biofuels production connected with very strong expectations of future further large expansion of biofuels driven by both government support policies and market forces. During this period, the refinery capacities and further infrastructure were in the process of expansion, generally lagging behind the increasing demand.

The strongest connection in the MST for this period is the one between American and European biodiesel. Important thing to notice here is the quite weak but very stable connection to rapeseed as the main feedstock. The second lowest pair is known to us from the previous MST – Dow Jones and SP 500 (0,294) with *b = 1*, while all of the stock indices form a very connected cluster. (See the connection between FSTE 100 and DAX along with DAX and SP 500). Very stable pair that will be seen in all of the periods is that of sugar cane and sugar beets with the distance of 0.321, which is quite understandable since the sugar from sugar beets and sugar cane is nearly identical (Kramer, 2016).

Figure 3: Minimum Spanning Tree - Period I



Source: Authors computations

Another quite common pair that is formed is that of Brent crude oil and WTI (0.424 with *b = 1*), which is not surprising since they are both seen as the global benchmark references for crude oil prices. They are followed by the connection of Brent crude oil with Heating oil (0.580 with *b = 1).* We can also observe that there is not an established connection between Heating oil and WTI, which would normally be there but since it would create a loop, the algorithm minimizing the number of links does not include it. Quite obvious but still very important connections are established between the gasolines and diesels, namely German diesel and gasoline (0.493), USA diesel and gasoline (0.693), and Brazilian diesel and gasoline (0,515). All of these relationships also showed to be very stable in the bootstrapped cases. The process then continues to create the whole MST in Figure 3.

In this figure, three clusters may be observed – that of fossil fuels connected to crude oils and heating oil, the financial assets such as stock indices, and biofuels that are connected to their feedstock. A very interesting link that can be seen throughout the whole period is that of Brazilian ethanol and sugar, which is so stable mainly due to the fact that Brazil's market was already quite established, since the production of biofuels begun in the 1970s. Another reason for that are the government interventions and subsidization (Koizumi 2003), while it is also related to the monopoly situation with Petrobras, which is seen as the only important market player for fuels. Also, biodiesel is already well connected to its feedstock, while USA ethanol is not yet connected to its major feedstock – corn.

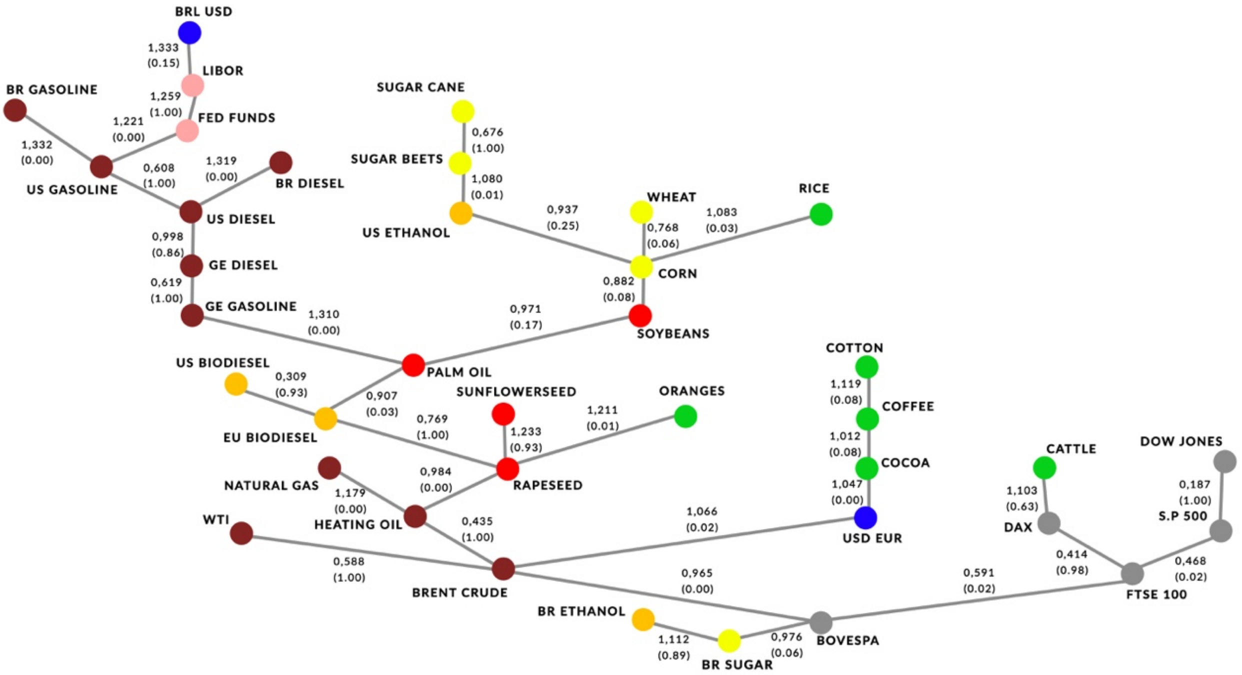
5.3 Period II – 9/2007 – 10/2011

This is a period of two major food crises in 2008 and 2011 which happened in a conjunction with the global financial crisis. The major policy characteristic of this period is a growing opposition against the biofuels expansion based both on environmental and food safety concerns. It is a period of non-stability of biofuels markets. While legislation strongly supporting biofuels is still in the place from the previous periods in some places or being introduced in another places, there is a growing momentum of expectation of possible future policy backslash against biofuels.

In this second period, we see a change in the layout of the MST as compared to the first period. The smallest link that we can find in the structure is the connection of Dow Jones and SP 500, with the distance of 0.187 and a very stable connection where $b = 1$. Second strongest relationship is represented by the USA and EU biodiesels, however, now the distance is a bit higher, 0.309, which illustrates their increasing independence, which could come from the market being more established and diverse.

As the biofuels market becomes more established in the USA as well, we can see the USA ethanol moving closer to its main feedstock – corn (0.937). This is a major change as compared to an initial biofuels market development period of 2003-2007. Therefore, after this relocation, every single biofuel in our MST is now closely connected to its feedstock.

Figure 4: Minimum Spanning Tree - Period II



Source: Authors' computations

Once again, we may see the clustering of stock indices – creating very strong and quite stable relationships. The stable relationship of Brazilian ethanol and sugar is still present, as was expected. In this period, Brent crude oil serves as a linkage of the main clusters, while still maintaining a very strong and stable relationship with WTI and Heating oil. What is quite interesting is the creation of "food cluster", where cocoa, coffee, and cotton are present. However, according to the bootstrapped values that we computed, this relationship is not that stable.

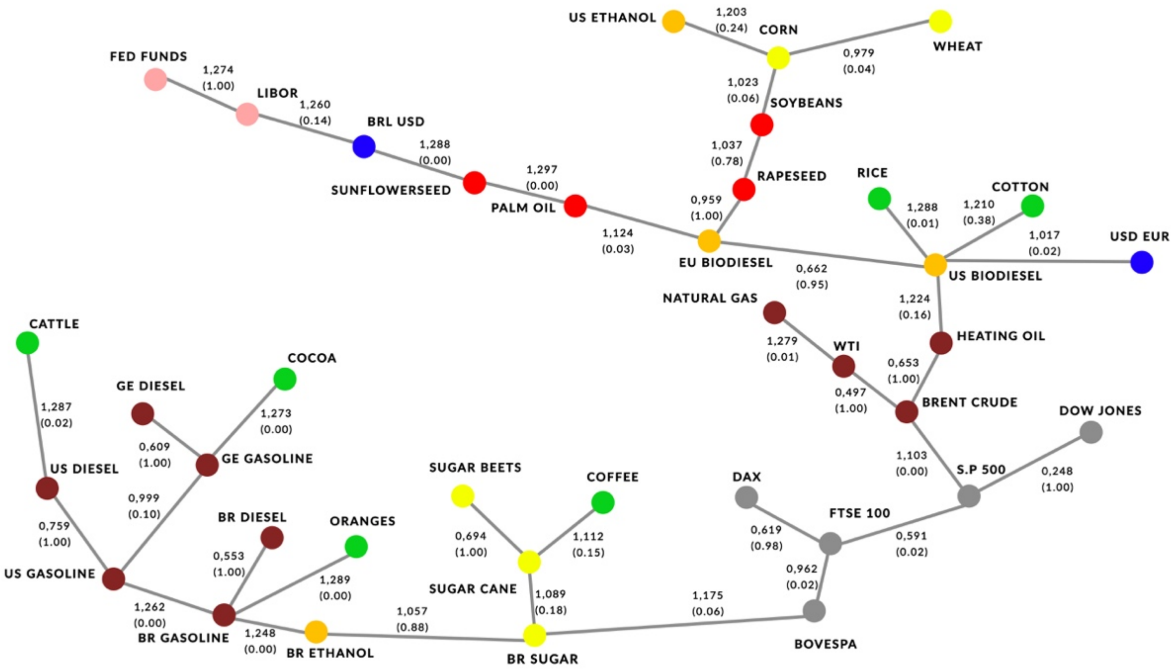
For biodiesel, strong technological based connection of the whole structure of biodiesel feedstock with both USA and EU biofuels continues from the previous period. However, we can see an increasing prominence of palm oil creating a direct link of EU biodiesel and palm oil, which could potentially be the result of Europe being one of the biggest importers of palm oil for the production of biofuels (Gerasimchuk and Koh 2013).

5.4 Period III – 11/2011 – 12/2015

This period after two food crises marks a sharp policy change for biofuels which moved from the position of a champion of agriculture related climate change mitigation policies into a position of commodities blamed for a number of problems from famine and impoverishment of farmers and consumers in developing countries to climate change policies failures (Timilsina, 2018). This was naturally connected with decreases of biofuels production in either absolute or relative form, depending on particular markets. An important feature of this period was the saturation of the biofuels markets with production facilities and other infrastructure.

Taking a closer look at this third period, we see that every biofuel keeps its connection to its main feedstock, and even though the relationships are slowly becoming less strong and stable, they are still present. Once again, we see a strong and stable relationship when it comes to the Brazilian market, where the fuels cluster was created, which will continue into the following Period IV. During this period, the USA ethanol and its main feedstock – corn, are still interconnected. As opposed to the previous period of food crises, food commodities are dispersed all over the MST, they do not seem to be closely connected to any of the biofuels and other assets, and in addition, the connections that are visible between foods and other assets do not possess any particular strength nor stability.

Figure 5: Minimum Spanning Tree - Period III



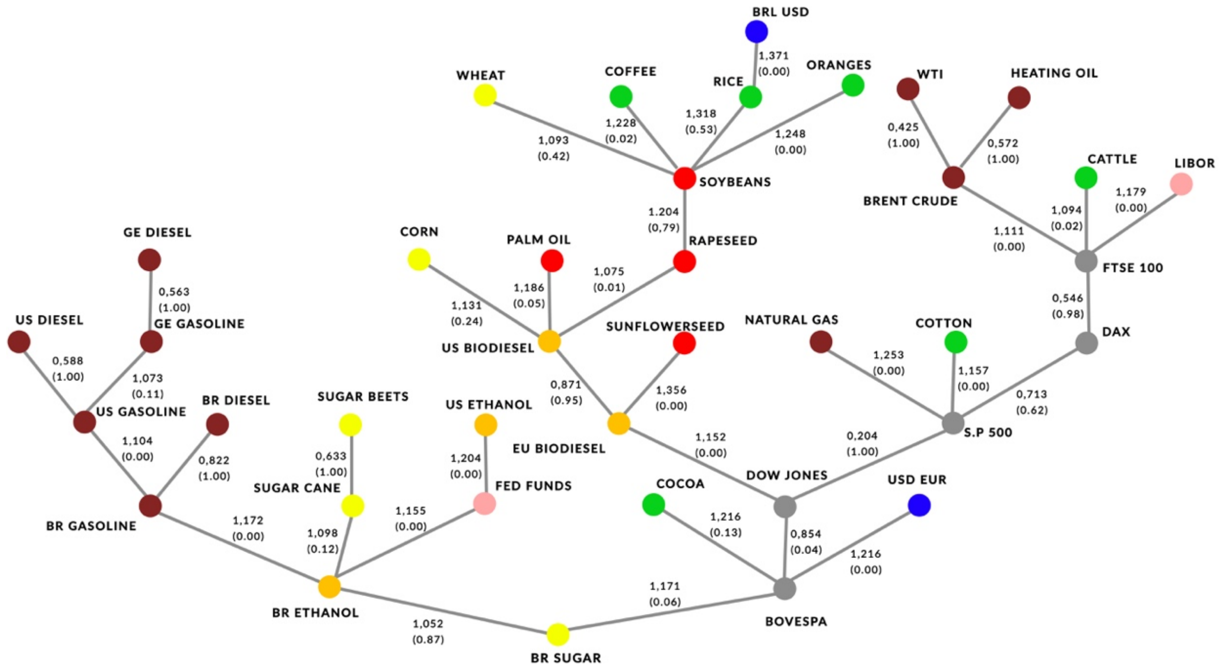
Source: Authors' computations

5.5 Period IV – 1/2016 – 4/2020

The period after 2016 can be characterized as return to a stable proportional development of both biofuels and agriculture in a stabilized policy environment. Looking at the Food Price Index that is included in the previous part, the prices of commodities and assets in this period seem to be without any increasing or decreasing trend and not very volatile. A major feature of this period of mature biofuels market is a close connection of both the USA and Brazilian ethanol, connected through the USA financial markets. This alignment of the USA and Brazilian ethanol prices also means that USA agricultural markets recovered from a period of ethanol production being the main driving force for US corn production.

Even after a relatively long period of development of USA ethanol and both USA and EU biodiesel, Brazilian ethanol and commodities and asset closely related to it still keep their central position of the most developed and best integrated biofuel system. Brazilian ethanol connects USA ethanol to a compact cluster of vehicle fuels and through Bovespa financial index connects with other major financial indexes to the oil branch of fossil fuels system.

Figure 6: Minimum Spanning Tree - Period IV



Source: Authors computations

Conclusion and Policy Implications

The comparison of our MSTs over the four distinct time periods shows an interesting change in the structure of price interconnection of biofuels and related assets and commodities along the global development of biofuels and related policies. At the initial period of biofuels development, it was clear that all fossil fuels considered in our analysis stood apart as a clearly defined and closely interconnected group without strong interaction with biofuels. So it was the time when agricultural commodities and fossil fuels were still much less connected.

During the 18 years covered by our analysis, we observe clear erosion of the initial firm cluster of fossil fuels. While the institutional decoupling of prices of natural gas and oil, driven by industrial organization policies rather than biofuel policies was a major force in driving natural gas away from the WTI/Brent crude/Heating oil cluster, the separation of highly processed vehicle fuels prices from the prices of non-vehicle raw oils is closely connected with advances of biofuels. This is particularly strong for ethanol which became closely aligned with vehicle fuels, mainly because of the mandatory blending requirement policies. For biodiesel, the different technological properties than ethanol leading to different blending policies mean that it is not as close to fossil vehicle fuels as ethanol, but it is still a part of a large vehicle fuels related cluster.

An important regularity over the whole investigated period is a close and stable direct connection between the EU and USA biodiesel together with their close connection with their feedstock. In the same way, we have documented a strong and stable direct connection between Brazilian ethanol and its sugar cane feedstock, which was represented by sugar. However, the USA ethanol behaved differently from other biofuels. It seems that a close connection of the USA ethanol and its major feedstock –corn – is not a natural stable situation. It happened only during the period of food crises and during the subsequent period of biofuels stagnation. Both in the initial period of biofuels market build-up and in a more recent period of biofuels market stabilization, the USA ethanol price was rather related to fossil fuels prices than to corn.

In addition to fossil fuels and biofuels closely related commodities, our results included two other big groups of prices which used to be related to biofuels in some of the previous literature. For the food commodities outside of biofuels feedstock group, our analysis clearly shows that in no period they were important for price transmission in a large biofuels/fuels system. However, for financial assets, the situation is different. While particular financial assets served as important connector for biofuels/fuels price transmission in different periods, they also became more systemically important for the whole biofuels/fuels system as a major connector between vehicle fuels and raw oil clusters which became separated over time due to the growing importance of biofuels in the fuels system.

Appendix

Table 1: Stationarity tests

	ADF	p-value	KPSS	p-value
BOVESPA	-9.296	<0.01	0.148	>0.10
BR DIESEL	-8.588	<0.01	0.134	>0.10
BR ETHANOL	-9.201	<0.01	0.168	>0.10
BR GASOLINE	-8.358	<0.01	0.082	>0.10
BR. SUGAR	-9.532	<0.01	0.269	>0.10
BRENT.CRUDE	-6.852	<0.01	0.472	0.04
BRL/USD	-8.144	<0.01	0.707	0.01
CATTLE	-8.807	<0.01	0.155	>0.10
COCOA	-9.738	<0.01	0.083	>0.10
COFFEE	-9.527	<0.01	0.255	>0.10
CORN	-9.204	<0.01	0.326	>0.10
COTTON	-8.508	<0.01	0.071	>0.10
DAX	-10.187	<0.01	0.095	>0.10
DOW JONES	-10.092	<0.01	0.066	>0.10
EU BIODIESEL	-7.985	<0.01	0.088	>0.10
FED FUNDS	-5.312	<0.01	0.174	>0.10
FTSE 100	-10.497	<0.01	0.111	>0.10
GE DIESEL	-8.968	<0.01	0.223	>0.10
GE GASOLINE	-8.789	<0.01	0.174	>0.10
HEATING OIL	-6.168	<0.01	0.521	0.04
LIBOR	-6.789	<0.01	0.335	>0.10
NATURAL GAS	-9.339	<0.01	0.065	>0.10
ORANGES	-9.228	<0.01	0.129	>0.10
PALM OIL	-8.44	<0.01	0.063	>0.10
RAPESEED	-8.742	<0.01	0.073	>0.10
RICE	-8.589	<0.01	0.069	>0.10
S.P 500	-9.981	<0.01	0.078	>0.10

SOYBEANS	-8.232	<0.01	0.098	>0.10
SUGAR BEETS	-9.334	<0.01	0.305	>0.10
SUGAR CANE	-9.164	<0.01	0.248	>0.10
SUNFLOWERSEED	-8.275	<0.01	0.051	>0.10
US BIODIESEL	-8.032	<0.01	0.205	>0.10
US DIESEL	-7.439	<0.01	0.348	>0.10
US ETHANOL	-10.507	<0.01	0.080	>0.10
US GASOLINE	-8.290	<0.01	0.177	>0.10
USD/EUR	-9.886	<0.01	0.121	>0.10
WHEAT	-10.226	<0.01	0.068	>0.10
WTI	-6.270	<0.01	0.423	0.07

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