The Pattern of Integration between Fossil Fuel and Vegetable Oil Markets: The Case of Biodiesel in Germany

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Abstract

With this paper, we provide the first quantitative investigation of vertical price transmission in the biodiesel supply chain in Germany with the focus on the developments during the food crisis and the impact of subsidized US biodiesel exports. With the strong promotion of the production and use of biodiesel during the first half of the past decade, the German biodiesel market became the largest national biodiesel market worldwide. This analysis utilizes prices of rapeseed oil, soya oil, biodiesel and crude oil over a sample period covering the rapid growth of the German demand in 2002 until its decline in 2009. The effects of both the market development and different policies on price transmission are analyzed in detail. Due to the numerous changes in the market, a regime-dependent Markov-switching vector error correction model is applied. The results indicate that regimes with differing error-correction behavior govern the transmission process among the various prices. Evidence was found for a strong impact of crude oil price on biodiesel prices, and of biodiesel prices on rapeseed oil prices. However, in both cases, the price adjustment behavior is found to be regime dependent, and the regime occurrence in both market segments shows similar patterns. In relation to crude oil a weak adjustment of biodiesel prices is found to be dominating in the phase of market expansion. This changed from 2007 on when stronger error-correction is found, reflected by a stronger role of the crude oil price developments. In the relationship of biodiesel to the vegetable oils, most of the growth period was dominated by a regime characterized by weak price adjustments. From 2007 on, past own price changes and past changes in soya oil prices had a strong impact particularly on rapeseed oil prices. The biodiesel price development was less important. Reasons for this are substantial changes in the market structure. The biodiesel market developed as an insulated market; biodiesel was mainly produced from rapeseed oil until 2006. Thereafter, biodiesel was increasingly used for blends and sales decreased during the food crisis when agricultural commodity prices rose sharply. At the same time, strong import competition arose from subsidized US B99. The superiority of rapeseed oil for biodiesel production diminished. The uncertainty prevailing in the market from 2007 onwards is reflected by frequent regime changes.

Keywords: Biodiesel, cointegration, nonlinear vector error correction model, regime-dependent model, Markov-switching.

JEL: C22, Q11, Q18

Introduction

The development of prices has been of interest to agricultural researchers for a long time, and various methods have been suggested to analyze the dynamics in price formation on interdependent markets. The central feature of integrated markets is that shocks to prices in one market are transmitted to other markets (Barrett, 1996). During the past years, a rising influence of energy markets on agricultural commodity markets was perceived (at least in public discussions), and the integration of the two markets has been increasingly investigated. The link is of particular importance for the much smaller agricultural market, because it not only implies potentially higher agricultural prices, but also the risk of volatility transmission from the crude oil market. De Gorter and Just (2008) analyzed the effects of those policy measures which were implemented to promote biofuels, on energy and agricultural markets. The results vary depending on the specific measure, or their combination. While the welfare effects are exhaustively discussed, the impact of these measures on the integration of both markets is not empirically investigated.

The integration of agricultural and energy markets and the existence of long-run price relations was analyzed for different commodities in various countries using price time series. Rapsomanikis and Hallam (2006) and Balcombe and Rapsomanikis (2008) found non-linear price adjustment in the Brazilian ethanol market using a threshold vector error correction model (TVECM). Serra et al. (2009) found cointegration in the US ethanol industry using a smooth transition VECM. Busse and Ihle (2009) found evidence for cointegration between biodiesel and the vegetable oil markets in Germany. The Markov-switching VECM (MS-VECM) revealed regime dependent price adjustment behavior. Peri and Baldi (2008) also found cointegration between rapeseed oil and gasoil prices in the EU using a TVECM. Hence, all authors found evidence for cointegration and determined that changes in energy prices cause changes in agricultural prices.

We add to the existing literature by focusing on the relationship between crude oil and biodiesel. Furthermore, the relationship between biodiesel, rapeseed oil and soya oil is analyzed. Both vegetable oils are considered because of their mutual substitutability in food and fuel use. The pricing is suspected to be strongly affected by changing policies and changes in market conditions. Since policy changes led to recurring changes in the market situation, the regime-dependent MS-VECM framework is applied. The article not only aims to study the integration of energy and agricultural markets; but to also to link different policy measures to changes in price transmission behavior.

The paper proceeds as follows. We first review the major market developments. Next, we derive hypotheses regarding the effects of changes in the policy framework on the extent of market integration. The specification of two Markov-switching vector error correction models is addressed in the third section. Subsequently, the estimation results are presented and discussed in detail. Finally, concluding remarks close the paper.

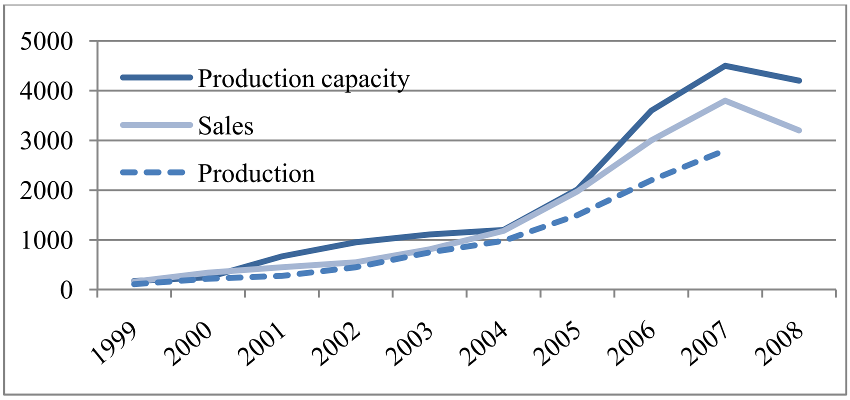
The biodiesel market

Market developments

On the global scale, the EU biodiesel market is currently the largest in the world. The development on the EU market is strongly governed by policy interventions. The EU set a binding target that 10% of all fuels placed on the market by 2020 must be biofuels; the Member States are responsible for reaching this target (D2003/30/EG). In Germany, the growth of the biodiesel industry was mainly encouraged by investment assistance and tax exemptions granted from 2004 onwards. Until 2003, the use of vegetable oil as fuel was unregulated and, therefore, tax free. As excess profits in the biofuel industry, resulting from this tax exemption, rose, the tax credit was reduced. An energy tax of 103 €/t of biodiesel sold as B100 (pure biodiesel), and a full taxation (541 €/t) for biodiesel used in blends was implemented in August 2006.

Since 2007, diesel must be blended with 5% (by volume) biodiesel (B5), which requires about 1.5 million tons of biodiesel. In case the target is not reached, a penalty of 690 € is charged for each ton of biodiesel required to reach the blending target. In comparison to this penalty, the production costs (estimated at 200 €/t by the German research council for agriculture, 2007) are comparatively low. Highest growth rates in sales occurred between 2004 and 2007 (Figure 1) which resulted in a large gap between domestic production and production capacity. Given the excess capacity in combination with increased import pressure, the capacity growth slowed down in 2007 and even turned negative in 2008. On the EU scale, production capacity was estimated at 16 million tones and the sales at 8 million tons in 2008 (EBB 2008) [1].

Figure 1: Production, production capacity and sales of biodiesel in Germany (1,000 tones)



Source: Own elaboration, based on UFOP (2010), VDO (2008), Biokraftstoffbericht (2008).

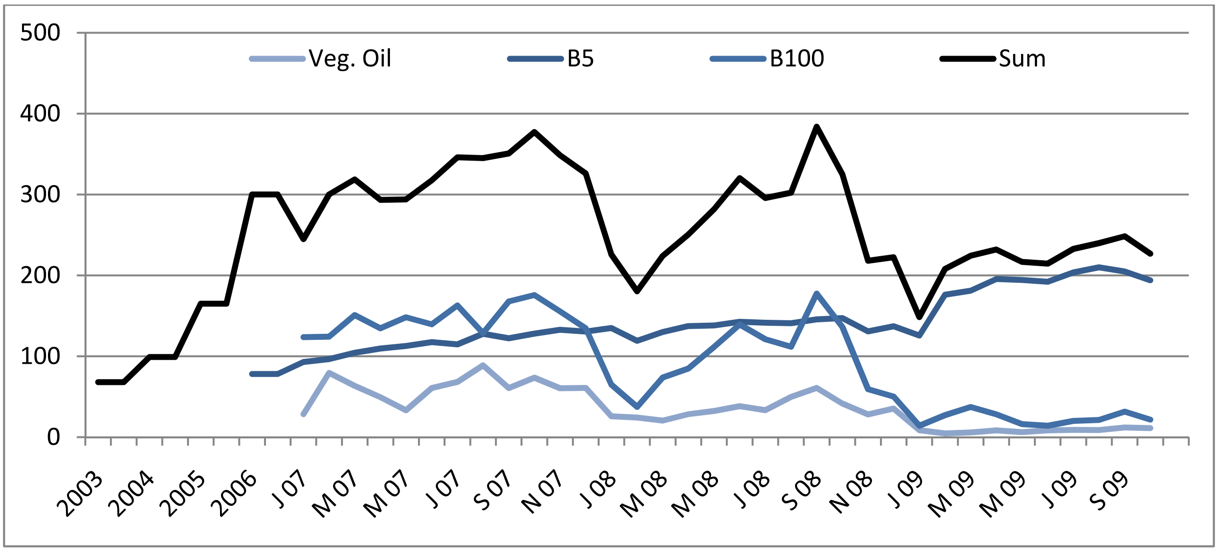
While mainly B100 was sold until 2005, the sales of B5 gained importance since 2006 when the market was challenged with taxation and increasing raw material costs. In 2007, the B5 market continued its growth and exceeded the B100 market volume (Figure 2). This resulted mainly from the need to fulfill the blending mandate. The raw material basis was initially almost exclusively rapeseed oil, as the use of other vegetable oils had been restricted by technical norms. The requirements concerning the Cold Filter Plugging Point (CFPP) especially make rapeseed oil most suitable. The use of high shares of other vegetable oils requires the use of additives and is easier during the summer months. The CFPP requirement applies for B100 as well as for B5, and effectively excludes palm oil from biodiesel use. However, soya oil shares of 20% and above have been used since 2006.

Particularly in the case of domestically produced rapeseed, the biodiesel sector became an important market where nowadays more than half of the domestically produced rapeseed is used. In the EU, biodiesel imports did not play an important role until 2007 but the import pressure from subsidized US B99 became in particular problematic in 2008 before penalty tariffs were raised. Subsidies for B99 were introduced by a US Federal Government program which aimed at increasing biodiesel production. The program specified an excise tax credit on diesel fuel and an income tax credit on biodiesel blends. The objective was to increase the

[1] While e.g. import tariffs and fuel norms account in all European countries, the implementation of fiscal measures is rather diverse. Several countries (e.g. Belgium, France, Greece, Ireland, Italy, or Portugal) define a quantity of biofuels which is eligible for tax credits or issue licences for these. While some countries only grant tax credits for blended fuels (e.g. Austria, Belgium and the Netherlands) other countries grant these only for pure biofuels (e.g. Germany, the Czech Republic and Luxembourg). However, most countries grant tax credits for both segments (for detailed overviews see e.g. Stratégie grains, 2008).

blending of biodiesel to fossil fuel. The blenders credit effectively subsidized biodiesel production with 300 $/t (~230 €/t) (USDA, 2007). The tax credits were not only granted to domestically used blended fuel but also to exports. Under this system re-exports of B99 (biodiesel blended with 1% fossil diesel) imported from third countries occurred (USDA, 2009).

Figure 2: Monthly sales of vegetable oil as fuel (B5 and B100) in 1,000 tons monthly average of annual sales 2003- 2006



Source: Own elaboration based on UFOP (2010).

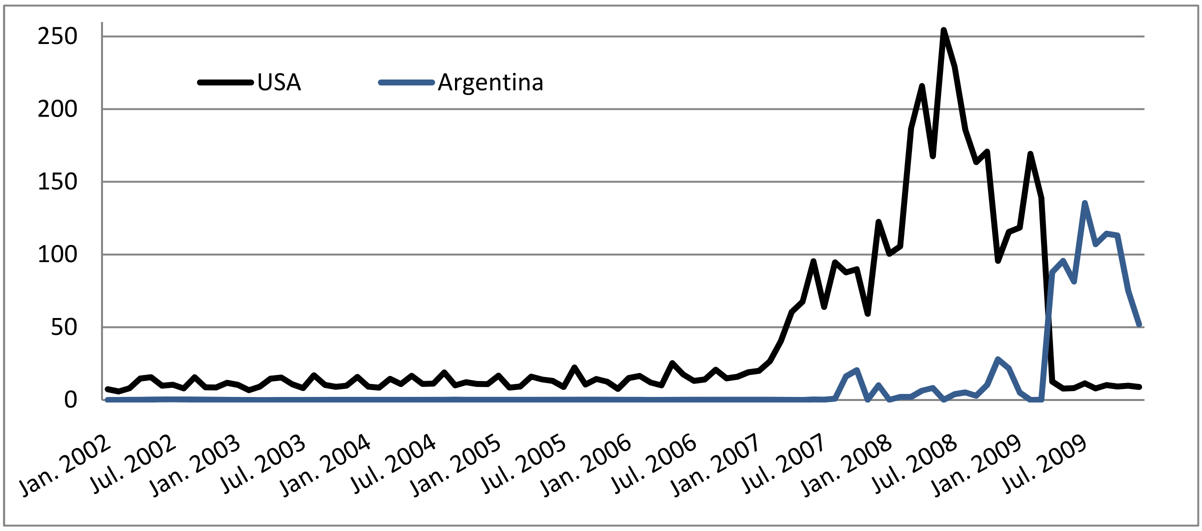
The EBB (2009) estimated that under this system up to 80% of biodiesel produced in the US ended in exports, predominantly to the EU. These subsidized exports were very competitive on the EU market (Their development can be seen in Figure 3). In March 2009 the EU introduced countervailing and antidumping duties on US imports (COM, 2009). The effect was a sharp decrease in biodiesel imports from the US (Figure 3). However, with the diminishing of the US exports, imports from other countries increased. Argentina took over a substantial share of the previous US share in the EU market.

Price developments

The development of weekly crude oil, biodiesel, rapeseed oil and soya oil prices between July 2002 and July 2009 is depicted in Figure 4 (358 observations in total). The vegetable oil and crude oil prices were obtained from The Public Ledger (2010). Soya oil and rapeseed oil prices are collected at Rotterdam harbor (Netherlands) as FOB (Free on board) prices for crude vegetable oil. The crude oil prices are Brent futures prices one month forward for crude oil FOB. The biodiesel prices are German consumer prices at the petrol station (UFOP, 2010).

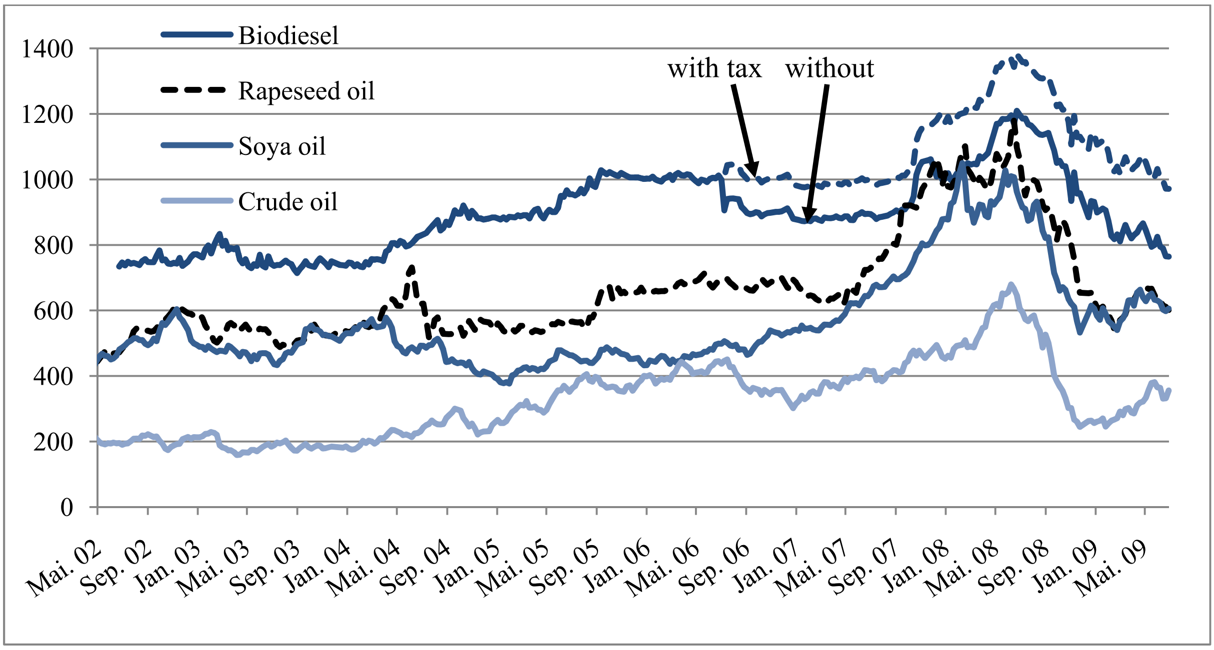
Since a petroleum tax was implemented in Germany in August 2006, biodiesel prices are used without this tax for comparison to vegetable oil. The tax is included when investigating its relationship with crude oil prices. This distinction appears in Figure 4 on the right hand side of the panel. All prices are in €/t net of VAT.

Figure 3: EU-imports of biodiesel from the USA and Argentina in 1,000 tones



Source: Eurostat (2010).

Figure 4: Prices of crude oil, biodiesel (with and without energy tax), rapeseed oil and soya oil in €/t



Source: Own figure, based on data from UFOP (2010) and The Public Ledger (2010).

All prices increased during the food crisis in 2007/08. Furthermore, a rising gap between rapeseed oil and soya oil prices from 2004 on becomes apparent. This is mainly due to the predominant use of rapeseed oil for biodiesel production. The gap reached its maximum in spring 2006 at 200 €/t before it started diminishing again. With the commodity price increase in 2007/08, rapeseed oil and soya oil prices increased sharply and converged to the level of biodiesel prices (without energy tax). In consequence, biodiesel production became uncompetitive. The result was e.g. a decrease of B100 sales and rapeseed oil in pure form for fuel (Veg. Oil) in Germany (Figure 2). Since the demand for B5 was enforced, these sales remained at an almost constant level.

Several hypotheses about the price behavior seem reasonable based on the discussed market development. A strong connection between the vegetable oil and crude oil prices via biodiesel should exist in the EU market since the major share of rapeseed oil is used for biodiesel production. The price gaps should be constant since production costs for biodiesel from vegetable oil are rather constant. In the relation between crude oil and biodiesel, it can be assumed that price impulses come from the much larger crude oil market and that biodiesel prices follow these trends. Furthermore, biodiesel has to compete with diesel, a derivative of crude oil. This price relation could have changed, since the biodiesel market changed from an independent, competitive market to a supplier of biodiesel for blends. Furthermore, the tax introduction and blending obligation could have an impact here. Additionally, the strong overcapacity, which was further aggravated by high commodity prices and increasing import competition from US B99 in 2007 and 2008, should have an impact.

In relation between rapeseed oil, soya oil and biodiesel, the rapeseed oil market appears to be the smallest and should therefore be mainly influenced by the others. Since the largest share of rapeseed oil is used for biodiesel and does not compete with soya oil on the food oil market, the impact of biodiesel price changes should be larger. On the other side, the soya oil market is a global market whereof the EU market represents only a small segment[2] and only parts of this are used for biodiesel. Hence, the biodiesel prices should not have a strong influence on soya price developments. However, soya oil gained importance for the biodiesel market as well as the rapeseed oil market from 2007 onwards when imports of US B99 increased. Changes in the price behavior can therefore be expected.

[2] The EU-27 used in 2008/09 about 8% of the world soya oil production (USDA, 2009)

Methodology

The basic idea of cointegration models is that economic variables such as prices are connected by long-run equilibrium relationships which tie together their development over time. The variables deviate from their equilibrium relationships in the short-run due to random shocks; however, these temporary deviations (the so-called equilibrium errors) are corrected over time. If no more short-run shocks would occur, the variables would tend towards their equilibrium values. One of the core assumptions of the traditional VECM is structural stability, i.e., all parameters of the data generating process are assumed to be constant. Parameter constancy is, however, unlikely under frequent changes in market conditions (Krolzig, 2002), as they occurred in the German biodiesel market. Besides pronounced political interventions, the quick growth of the biodiesel market and the increased usage of rapeseed oil for fuel production instead of food, cast doubt on the assumption of constant parameters in the given context.

Market dynamics and developments are driven by expectations based on implemented policies, and are geared towards expected policy changes. Hence, economic agents can change their behavior according to their expectations before a new framework of policy measures comes into force. They may also maintain certain behavior after a policy framework is abolished or replaced by a new one, e.g., due to investments undertaken, or based upon implemented policy measures, which may create and strengthen incentives. Thus, changes in the dynamics and interactions of price behavior as the sum of collective action of many economic agents do not necessarily coincide with the timing of policy changes.

The difficulty of identifying and quantifying potential changes in the structural relationships of the variables (regime switches) and the factors inducing them favors a modeling strategy alternative to the traditional VECM. An appropriate model would allow parameters to take different values depending on the current regime of the price behavior, i.e., the underlying economic relationships. Due to the complexity of markets, *a priori* identification and measurement of the factors causing the switches and their occurrence dates can be difficult if possible at all.

A variety of regime-dependent models have been proposed in the existing literature, e.g., the TVECM (Balke and Fomby, 1997; Lo and Zivot, 2001), the smooth transition VECM (Teräsvirta, 1994) or the parity bounds model (Baulch, 1997). None of them seems ideally suitable for our study, as discussed above. The two former model classes require the identification and the measurement of the factors inducing the regime switches. Additionally, the latter class, among others, leaves the switching mechanism completely unexplained and also disregards the time series properties of the data. The MS-VECM appears to be an alternative to these modeling strategies since it does not require the specification of the switching variables but still models the switching mechanism in a meaningful way. Moreover, the development of the markets studied is determined by a number of exogenous factors as discussed above. This corresponds closely to the basic idea of the MS-VECM where regime switches are assumed to be induced by an exogenous stochastic process (Ihle and von Cramon-Taubadel, 2008).

The MS-VECM, as a regime-dependent time series model, was initially developed by Hamilton (1989). Krolzig (1997) gives a detailed account of the usage of the model in economic analysis. Regime-dependent models allow for a non-linear data generating process which is characterized by non-constant parameters. In the case of Markov-switching time series models, it is assumed as piecewise linear, i.e., each parameter takes a constant value in each regime; however, it is allowed to take different values across the regimes. Hence, the key difference between the VECM and the MS-VECM is the assumption of the stability of model parameters. These are restricted to be invariant across regimes in the former case but allowed to be regime-dependent in the latter. The strengths of the MS-VECM approach lie in its ability to identify potentially latent regimes in the data, and its enormous flexibility in model specification.

The model has been used throughout socio-economic research although Markov-switching time series models are most frequently used in business cycle and finance research. Notable examples include Jackman (1995), who analyses presidential approval in the US. Hall et al. (1997) study housing prices in the UK using a MS-VECM. Additionally, Morais and Portugal (2004) study regimes in the Brazilian import demand while Brümmer et al. (2009) investigate the integration of wheat and flour prices in Ukraine[3].

For analyzing price transmission in the German biodiesel complex, it seems plausible to allow the vector of intercepts (a), the loading matrix α (containing the magnitudes at which deviations from the long-run equilibrium are corrected) and the matrices Γ_i (containing the short-run price reactions), to be regime-dependent. Hence, we start from the following MS-VECM specification:

[3] For a more detailed review of the existing literature see Ihle (2010).

$$\Delta p_t = a(s_t) + \alpha(s_t)\,(\beta' p_{t-1}) + \sum_{i=1}^{k} \Gamma_i\,(s_t)\Delta p_{t-i} + u_t \qquad (1)$$

where $p_t = (p_t^{Ro} \;\; p_t^{BD} \;\; p_t^{So})'$ is the vector of market prices of the three commodities. β represents the cointegrating vectors describing the long-run equilibriums of the prices, Δ denotes the first difference operator, and u_t white noise residuals with regime dependent variance $\sigma_u^2(s_t)$.

Regime-dependence is represented by the state variable $s_t \in \{1, \dots, M\}$ indicating which of the M regimes governs the system at time t. This regime variable does not have to be observed so that the current state of the system is unknown a priori. The model assumes regime-wise linearity. Thus, the regime-dependent parameters, e.g. the intercept vector a, are allowed to take a different constant value in each regime s_t:

$$a\,(s_t) = \begin{cases} a_1 & if\ s_t = 1 \\ \vdots & \\ a_M & if\ s_t = M \end{cases} . \qquad (2)$$

The stochastic process generating the regimes is assumed to follow a Markov chain. Thus, the probability of switching between two regimes in subsequent periods is independent of the history of the process before these periods, i.e., “the past should have no influence on the future except through the present” (Chung, 1960). The Markov chain is assumed to be ergodic, which ensures a stationary distribution of the regimes, and irreducible, which ensures that any regime can be reached from any other regime, i.e. no absorbing regimes exist. Furthermore, we assume the Markov chain to be homogenous, i.e., having constant transition probabilities:

$$\pi_{ij} = \Pr(s_{t+1} = j | s_t = i)\,, \quad \pi_{ij} > 0 \quad \forall\, i,j \in \{1, \dots, M\}\,; \quad \sum_j \Pi_{ij} = 1 \qquad (3)$$

The transition probabilities quantify the probabilities for switching from regime i in period t to regime j in period $t + 1$. All M^2 probabilities are summarized in the transition matrix Π, containing the probability π_{ij} in the ith row and the jth column.

Due to the two stochastic processes incorporated in the model, i.e. the process generating the time series dynamics in each regime and the one generating the switches between the regimes, two types of adjustment exist. In each regime, deviations from the long-run equilibrium are corrected by the error-correction mechanism towards the long-run price equilibriums. The errors arising from the regime switches are corrected towards the stationary distribution of the regimes (Krolzig, 2003). Based on (3), it becomes obvious that the regime switches are not considered to be singular deterministic events which would correspond to absorbing regimes. They are rather thought of as recurring structural changes which occur in a stochastic fashion and lead to alternating regimes which last for a limited period. Hamilton (1989) characterizes this switching mechanism as "discrete shifts in regime-episodes across which the dynamic behavior of the series is markedly different". Hamilton and Raj (2002) argue that "the normal behavior of economies is occasionally disrupted by dramatic events that seem to produce quite different dynamics for the variables that economists study".

This class of models is usually, as in this article, estimated by the expectation maximization algorithm (EMA) developed by Dempster et al. (1977) and Hamilton (1990). The EMA consists of two steps, which in turn evaluate the probabilities of the regime occurrence and the parameter estimates up to convergence. Details of the calculation are provided in Krolzig (1997, chapter 6). In recent years, the model class has been increasingly estimated with Bayesian methods (see Balke and Wohar, 2009 or Frei, 2008, among others).

The regime incidences can be reconstructed by inferring the probabilities of the occurrence of the unobserved regimes conditional on the full information available in the sample. These so-called smoothed probabilities provide the likelihood of occurrence of each regime at time *t* based on the entire sample information. Such probabilistic instead of deterministic statements reflect the uncertainty which is inherent to any assignment of observations to regimes. Hamilton (1989) suggested using 0.5 as the probability for regime classification.

Empirical results

Unit root and cointegration tests

Crude oil, biodiesel, rapeseed oil and soya oil prices are initially tested for unit roots using the Augmented Dickey-Fuller Test (ADF) and the Kwiatkowski, Phillips, Schmidt & Shin Test (KPSS). Both tests give strong evidence for the presence of unit roots in all series[4]. Cointegration is tested using the Johansen trace test and the Saikkonen-Lütkepohl (2000) test. Strong evidence is found for cointegration between crude oil and biodiesel prices and between rapeseed oil, soya oil and biodiesel prices jointly. Hence, the price pair crude oil and biodiesel

[4] Test statistics are available from the authors upon request.

is investigated to link biodiesel prices to energy prices. Second, the relationship between biodiesel, rapeseed and soya oil prices is investigated in order to analyze the relationships between biodiesel and its raw materials.

VECM estimation results for biodiesel and crude oil prices

In the estimation, the price levels will be used which explicitly implies that additive processing costs need to be assumed in vertical price transmission. The constant in the estimated equation reflects fixed processing costs. The multiplicative part shows the influence of price changes in absolute terms. These can either contain processing costs or in multivariate systems the influence of single market segments. In the bivariate system, a slope coefficient of one would reflect constant processing costs and a full transmission of price changes, presumably without any by-products involved. In the multivariate system, the slope coefficients show the partial impact of the other prices; however, the interpretation of the constant depends on the structure of the system estimated. The estimation in logarithms is an alternative in which the slope coefficients could be interpreted as elasticities. However, a multiplicative relation needs to be assumed which also implies multiplicative processing costs. Since our sample period covers a phase of considerably high prices, it seems reasonable to use price levels in order to ensure feasible values for the processing costs.

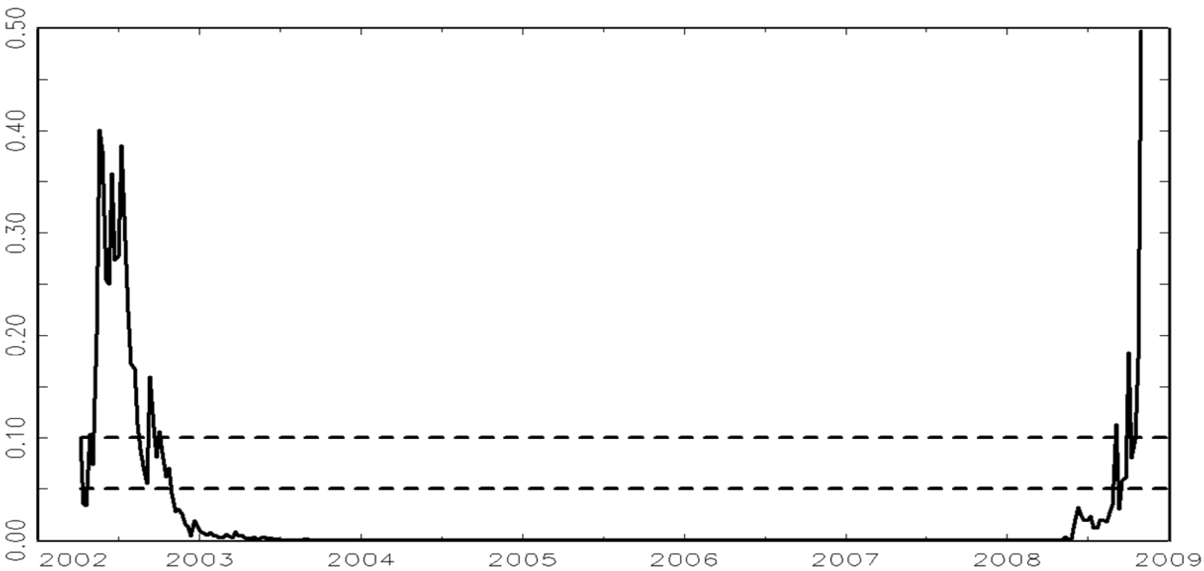
First, we estimate a VECM with two lags to derive the long-run relationship of biodiesel and diesel prices (standard errors in parentheses):

$$P_t^{BD} = \underset{(39.04)}{473.55} + \underset{(0.112)}{1.514}\, P_t^{CO} + ect_t^{I} \quad . \qquad (7)$$

Since the crude oil prices are tax free, the constant (474 €/ t ~37 ct/l) represents roughly the energy tax, which is added on diesel (47 ct/l) minus the widely assumed buying incentive (10 ct/l). The high multiplier (1.51), which deviates significantly from 1, can partly reflect the processing costs for diesel. However, it indicates that the biodiesel prices rise more strongly than the crude oil prices themselves. As expected, significant error-correction is found in biodiesel prices only ($\alpha = -0.057$ (0.010)).

Residual tests of this linear VECM indicate problems with heteroskedasticity and excess kurtosis. In order to test for parameter stability, we conduct a break-point Chow test on all model parameters[5]. The approach searches over each data point based on 2,000 bootstrap replications. The null hypotheses of parameter constancy can be rejected at any point in time between 2003 and 2008 at the 5% level (see Figure 5). When applying the recursive eigenvalue test, the null hypothesis of stability vectors α and β over time cannot be rejected at a distinct point in time. Thus, there is no evidence for a change in the long-run behavior but there is strong support that the existence of a stable long-run equilibrium is found. Both the residual as well as the stability analysis strongly suggest that a linear VECM does not fit the data[6].

Figure 5: P-values of the bootstrapped break-point Chow test (biodiesel – crude oil)



Source: Own calculations.
Note: A value below the lower (upper) dotted line indicates the rejection of the parameter constancy hypothesis at the 5% (10%) level of significance.

VECM estimation results for biodiesel, rapeseed and soy oil prices

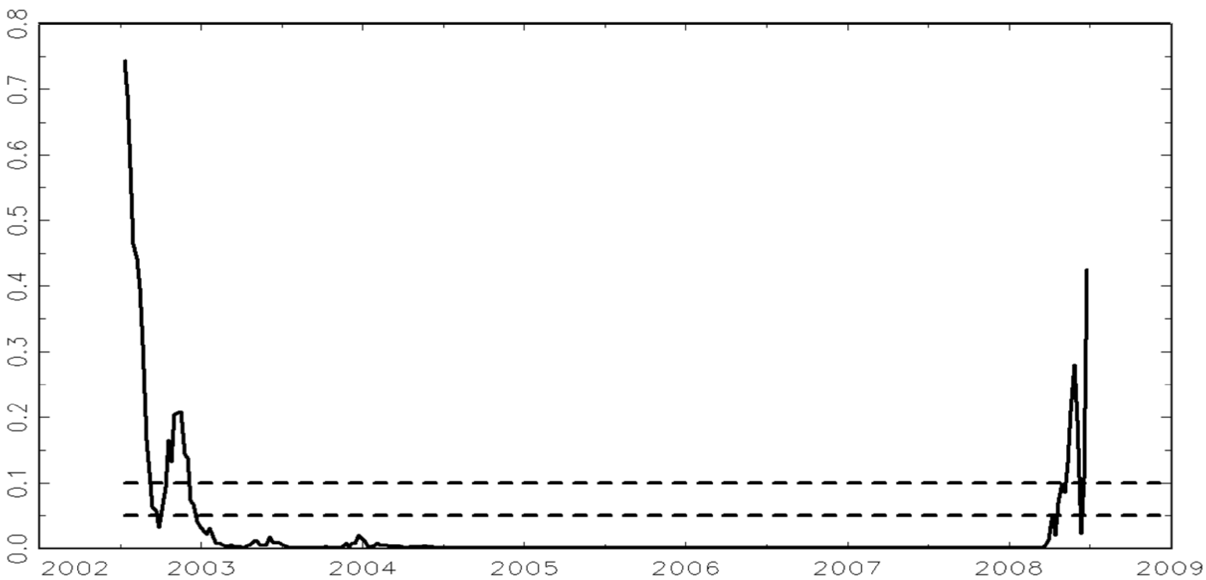
The second long-run relationship of biodiesel with rapeseed and soy oil prices is estimated as follows using 5 lags (standard errors in parentheses):

$$P_t^{Ro} = \underset{(65.07)}{-267.99} + \underset{(0.087)}{0.592}\, P_t^{BD} + \underset{(0.067)}{0.711}\, p_t^{So} + ect_t^{II} \quad . \qquad (8)$$

[5] Hence, we allow the covariance matrix of the residuals to differ but maintain regime invariance for the cointegrating vector β
[6] The according test statistics can be obtained from the authors upon request.

Corrections of deviations from the long-run equilibrium are shown by rapeseed and soya oil prices. The influence of soya oil prices appears to be higher than that of biodiesel prices. A price increase of 100 €/t in biodiesel would lead to an increase in rapeseed oil prices by 59 €/t, the same increase in soya oil prices would increase the rapeseed oil price by 71 €/t in the long-run. The residual analysis of this model indicates, again, problems with heteroskedasticity and non-normality. The null hypotheses of parameter constancy of the break-point Chow test can be rejected for most of the possible breakpoints between 2003 and 2008 at the 5% level (Figure 6). The recursive eigenvalue test again, does not indicate instability in the long-run relationship.

Figure 6: P-values of the bootstrapped break-point Chow test, biodiesel – vegetable oils



Source: Own calculations.
Note: A value below the lower (upper) dotted line indicates the rejection of the parameter constancy hypothesis at the 5% (10%) level of significance.

MS-VECM estimation results for biodiesel and crude oil

In the next step, we estimate a regime-dependent MS-VECM because it represents a reasonable choice of a suitable approach for modelling time series dynamics subject to changing complex economic and political influences. For estimation, the MSVAR-package Version 1.31k for Ox is used (Doornik, 2002). We estimate a MSIAH(3)-VECM for the biodiesel and crude oil price pair[7]. It allows for Markov-switching in the error-correction

[7] This specification is suggested by the Akaike information criteria (AIC) in comparison to alternative specifications w.r.t. lag length and more restrictive Markov specifications

coefficients, the intercept (I), autoregressive parameters (A), and in the standard errors of the equations (heteroskedasticity, H) between the three regimes (3). The model is estimated using two lags, based on exclusion tests for higher order lag coefficients. The diagnostic tests indicate normally distributed residuals, and the absence of autocorrelation and heteroskedasticity; hence, the model seems appropriate for the data. The parameter estimates are shown in Table 1.

The three estimated regimes show different characteristics in the adjustment behavior, i.e. the estimated α parameters. While the first two regimes show similar behavior, the third regime shows rather unusual price behavior. This regime is labeled “Turn” regime since it shows a strong tendency to correct previous own price changes and to follow the others past price change. It consists of only 8 observations and is characterized by an average duration of 1.3 weeks. Due to the very small number of observations, interpretation lacks foundation. This regime is, thus, not discussed in the further analysis.

Table 1: Estimated coefficients of the MSIAH(3)-VECM for crude oil and biodiesel

	Strong adjustment regime		Weak adjustment regime		Turn regime	
	Δp^{BD}	Δp^{CO}	Δp^{BD}	Δp^{CO}	Δp^{BD}	Δp^{CO}
Const	50.55*** (8.13)	-6.79 (7.66)	9.45** (4.17)	0.49 (5.70)	93.68*** (31.53)	-49.99** (20.81)
Δp^{BD}_{t-1}	-0.1734** (0.0713)	-0.0372 (0.0647)	-0.2885** (0.1134)	-0.1206 (0.0817)	-0.6524*** (0.2044)	0.0885 (0.1349)
Δp^{BD}_{t-2}	0.0037 (0.0684)	-0.0548 (0.0585)	-0.3940*** (0.1020)	-0.0691 (0.0705)	-0.5980* (0.3586)	0.9288*** (0.2368)
Δp^{CO}_{t-1}	0.4512*** (0.0953)	0.4201*** (0.0870)	0.0932 (0.0798)	0.0761 (0.0820)	0.3550 (0.2382)	-0.6736*** (0.1572)
Δp^{CO}_{t-2}	0.0521 (0.0979)	0.1446 (0.0925)	0.1189* (0.0660)	-0.0146 (0.0855)	0.7965*** (0.2993)	0.1481 (0.1976)
α	-0.1052*** (0.0167)	0.0116 (0.0156)	-0.0214** (0.0094)	0.0037 (0.0126)	-0.1006* (0.0602)	0.1042** (0.0397)
SE	14.24	13.18	7.39	9.36	15.29	10.10
Constant restricted	**-480.51**	-585.35	**-441.59**	132.43	**-931.21**	**-479.75**
# Obs.	155		192		8	

Source: Own calculations.
Note: Standard deviation in parentheses; asterisks denote significance at the 1%(***), 5%(**) and 10%(*) level

The first two regimes show the expected behavior that crude oil prices do not react to changes in biodiesel prices. These two regimes can be discriminated with respect to the biodiesel price behavior. Two distinct adjustment processes appear. The first regime is labeled "Strong adjustment" since a substantially stronger error-correction is found here ($a^{BD} = -0.105$) compared to the second regime ($a^{BD} = -0.021$), which is termed "Weak adjustment", correspondingly. When ignoring any short-run adjustment, half of a deviation from equilibrium would be corrected in the "Weak adjustment" regime within 33 weeks. This, however, needs less than 7 weeks in the "Strong adjustment" regime. Furthermore, the short-run price behavior differs. While the largest impact comes from past crude oil price changes in the "Strong adjustment" regime, the "Weak adjustment" regime shows strong reactions to past own price changes. Hence, the biodiesel market seems more autonomous in this regime.

The estimated transition probabilities are given in Table 2. Given the Markov-chain is in the "Weak adjustment" regime, it has a 90% probability to stay in and a 10% probability to leave it and switch to the other regime. While the "Weak adjustment" regime lasts for 10 weeks on average, the "Strong adjustment" regime is less persistent with an expected duration of only 7 weeks.

Table 2: Transition matrix for the MSIAH(2)-VECM for biodiesel and crude oil

to… from...	Strong adjustment regime	Weak adjustment regime	Turn regime
Strong adjustment regime	0.859	0.102	0.034
Weak adjustment regime	0.099	0.901	< 0.001
Turn regime	0.388	0.374	0.238

Source: Own calculations.

MS-VECM estimation results for biodiesel, rapeseed and soy oil

For investigating the relationship between biodiesel, rapeseed and soya oil prices, we estimate a MSAH(2)-VECM as indicated by the Akaike information criteria (Table 3)[8]. The diagnostic tests indicate the absence of autocorrelation, however, heteroskedasticity still remains. The

[8] This shows a slightly better result for a 3 regime specification (24.643 vs. 24.664), however, due to the number of parameters which have to be estimated including 5 lags, the more parsimonious specification is chosen

error-correction speeds (α) do not vary substantially between the two regimes and therefore do not represent the main discriminating characteristics. The rapeseed oil prices show higher error-correction behavior. However, values between 0.072 and 0.048 indicate half lives of 10 to 15 weeks, which is fairly slow.

Both regimes show very different short-run behavior. The second regime shows in most cases higher values than the first regime. In the first regime, the soya oil prices show no significant reactions to past changes of own prices or of rapeseed oil and biodiesel prices. In the second regime, past rapeseed oil price changes have a negative impact on current changes while past own price changes have a positive impact. The prices therefore do not seem to be dominated by rapeseed or biodiesel prices. However, soya oil prices show in both cases significant error-correction towards the long-run equilibrium with the other two prices. Biodiesel prices show no significant error-correction behavior. Its short-run behavior does not allow for a systematic distinction between the two regimes.

Quite distinct is, on the other hand, the difference in the short-run behavior of rapeseed oil prices. The first regime shows a moderate impact of past rapeseed oil price changes as well as soya oil and biodiesel price changes. The second regime shows a considerably stronger impact of past rapeseed price changes on rapeseed prices. Furthermore, past soya oil price changes seem to play an important role. Due to the stronger influence of biodiesel prices on the vegetable oil price development, the first regime is labeled "Biodiesel" regime. In the second regime, all prices react strongly to past changes in vegetable oil prices. The regime is therefore labeled "Veg. oil" regime. The estimated transition probabilities are given in Table 4. While the "Veg. oil" regime lasts on average less than 6 weeks, the biodiesel regime exceeds 8 weeks.

Table 3: Estimated coeffs. of the MSAH(2)-VECM for biodiesel, rapeseed and soya oil

Variable	Biodiesel regime			Veg. oil regime		
	Δp^{Ro}	Δp^{So}	Δp^{BD}	Δp^{Ro}	Δp^{So}	Δp^{BD}
Const	-17.98*** (5.25)	11.60** (4.49)	4.07 (4.17)	-17.98*** (5.25)	11.60** (4.49)	4.07 (4.17)
Δp^{Ro}_{t-1}	0.1106* (0.0596)	0.0405 (0.0449)	-0.0625 (0.0428)	0.6774*** (0.0931)	-0.0826 (0.1038)	0.0514 (0.1087)
Δp^{Ro}_{t-2}	-0.1400** (0.0588)	-0.0349 (0.0442)	0.0669 (0.0427)	-0.4779*** (0.1045)	0.0942 (0.1136)	-0.0465 (0.1185)
Δp^{Ro}_{t-3}	0.2362*** (0.0669)	0.0727 (0.0508)	-0.0060 (0.0480)	0.0131 (0.0928)	-0.3435*** (0.1056)	-0.0058 (0.1100)
Δp^{Ro}_{t-4}	0.0432 (0.0680)	-0.0050 (0.0511)	0.0859 (0.0526)	-0.2075** (0.0922)	0.0075 (0.1018)	-0.0776 (0.1071)
Δp^{Ro}_{t-5}	0.1164 (0.0733)	0.0926 (0.0568)	0.0141 (0.0514)	0.1189 (0.0794)	-0.1192 (0.0880)	0.2494*** (0.0928)
Δp^{So}_{t-1}	0.1624** (0.0789)	0.0695 (0.0613)	0.1387** (0.0571)	0.1165 (0.0894)	0.3647*** (0.0995)	0.1311 (0.1051)
Δp^{So}_{t-2}	-0.1225 (0.0771)	0.0464 (0.0549)	0.0057 (0.0572)	0.0642 (0.0998)	-0.1739 (0.1087)	0.2414** (0.1144)
Δp^{So}_{t-3}	-0.0547 (0.0731)	0.0463 (0.0596)	-0.1048** (0.0532)	0.2643*** (0.0933)	0.2192** (0.1052)	-0.1238 (0.1099)
Δp^{So}_{t-4}	-0.1050 (0.0843)	-0.0191 (0.0550)	0.1058** (0.0519)	-0.1623 (0.1012)	0.0865 (0.1068)	0.0988 (0.1135)
Δp^{So}_{t-5}	0.0294 (0.0783)	0.0660 (0.0610)	0.0718 (0.0572)	0.1964** (0.0928)	-0.0348 (0.1038)	-0.0534 (0.1113)
Δp^{BD}_{t-1}	-0.1290* (0.0717)	0.0358 (0.0542)	-0.1976*** (0.0553)	0.1259 (0.0779)	0.1242 (0.0875)	-0.1766* (0.0921)
Δp^{BD}_{t-2}	0.0802 (0.0646)	0.0893* (0.0518)	-0.1402*** (0.0463)	0.0342 (0.0861)	-0.0553 (0.0948)	0.0711 (0.1005)
Δp^{BD}_{t-3}	-0.0785 (0.0610)	0.0368 (0.0454)	-0.0100 (0.0434)	0.1427 (0.0871)	0.1300 (0.0987)	0.0270 (0.1034)
Δp^{BD}_{t-4}	0.0663 (0.0577)	-0.0415 (0.0455)	-0.0146 (0.0401)	0.0696 (0.0923)	0.0672 (0.1024)	0.1904* (0.1093)
Δp^{BD}_{t-5}	0.1280** (0.0588)	0.0527 (0.0424)	0.0251 (0.0384)	-0.0329 (0.1005)	0.0157 (0.1039)	0.1000 (0.1086)
α	-0.0723*** (0.0198)	0.0420** (0.0168)	0.0183 (0.0158)	-0.0584*** (0.0197)	0.0481*** (0.0174)	0.0133 (0.0164)
SE	10.827	8.105	7.561	19.005	21.892	22.832
Constant restricted	**248.69**	**276.19**	222.40	**307.87**	**229.94**	306.02
# Obs.		211			141	

Source: Own calculations.
Note: Standard deviation in parentheses; asterisks denote significance at the 1%(***), 5%(**) and 10%(*) level

Table 4: Transition matrix for the MSAH(2)-VECM for biodiesel, rapeseed and soya oil

	to…	
from...	Biodiesel regime	Veg. oil regime
Biodiesel regime	0.878	0.122
Veg. oil regime	0.178	0.8218

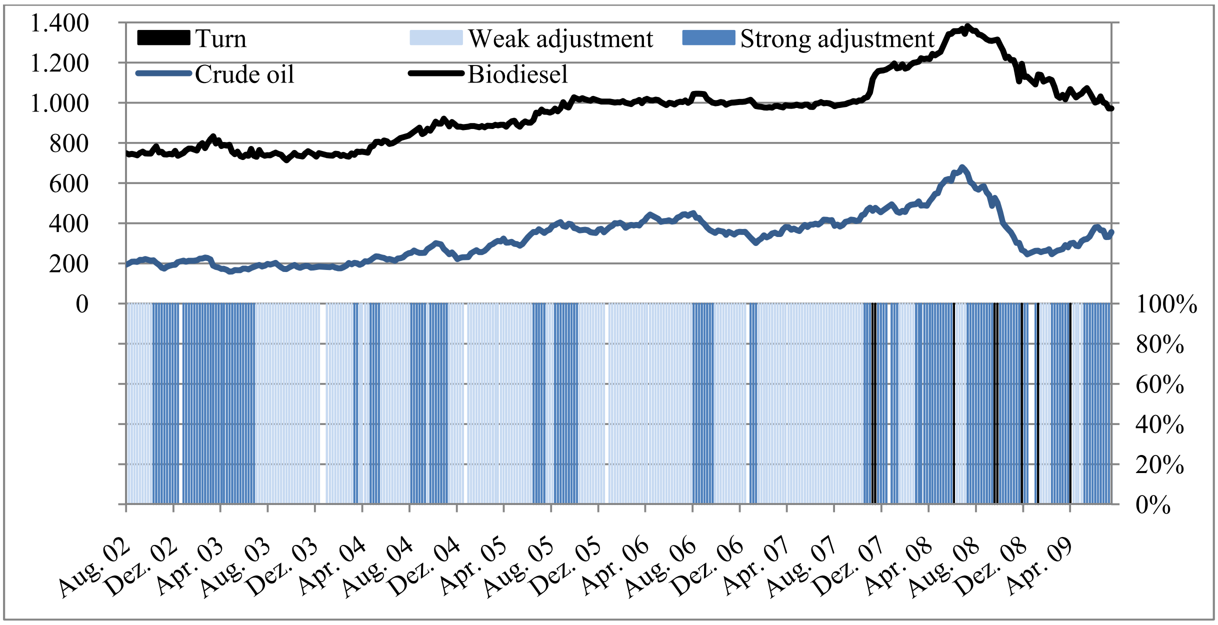
Source: Own calculations.

Discussion

The regime classification in the relationship between crude oil and biodiesel prices is plotted in Figure 7. The assignment is made based on the highest probability of regime occurrence among the three regimes. It can be seen that the "Strong adjustment" regime, which is characterized by the strong influence of crude oil prices on the development of biodiesel prices, was mainly present in the beginning and the end of the sample period. The sample starts with the development of the biodiesel market in 2002. Production as well as sales increased rapidly in Germany during the first years with a doubling of production capacity annually between 2004 and 2006. However, especially in this phase of strong growth, the "Strong adjustment" regime was seldom observed.

The period between 2003 and 2007 is dominated by the "Weak adjustment" regime, where biodiesel prices error-correct slowly and react mostly to own price changes. Furthermore it becomes apparent that the duration of the regimes is dominated by periods of several months up to the end of 2007. However, from 2008 on, when the food price crisis occurred and the prices of both commodities were markedly increased, regime duration appears to be much shorter, often lasting less than one month. The occurrence of the "Turn" regime during this phase in addition to the frequent regime switches can be seen as one aspect of the increased uncertainty in the markets during this period.

Figure 7: Biodiesel and crude oil prices (left scale) and regime occurrence (right scale)



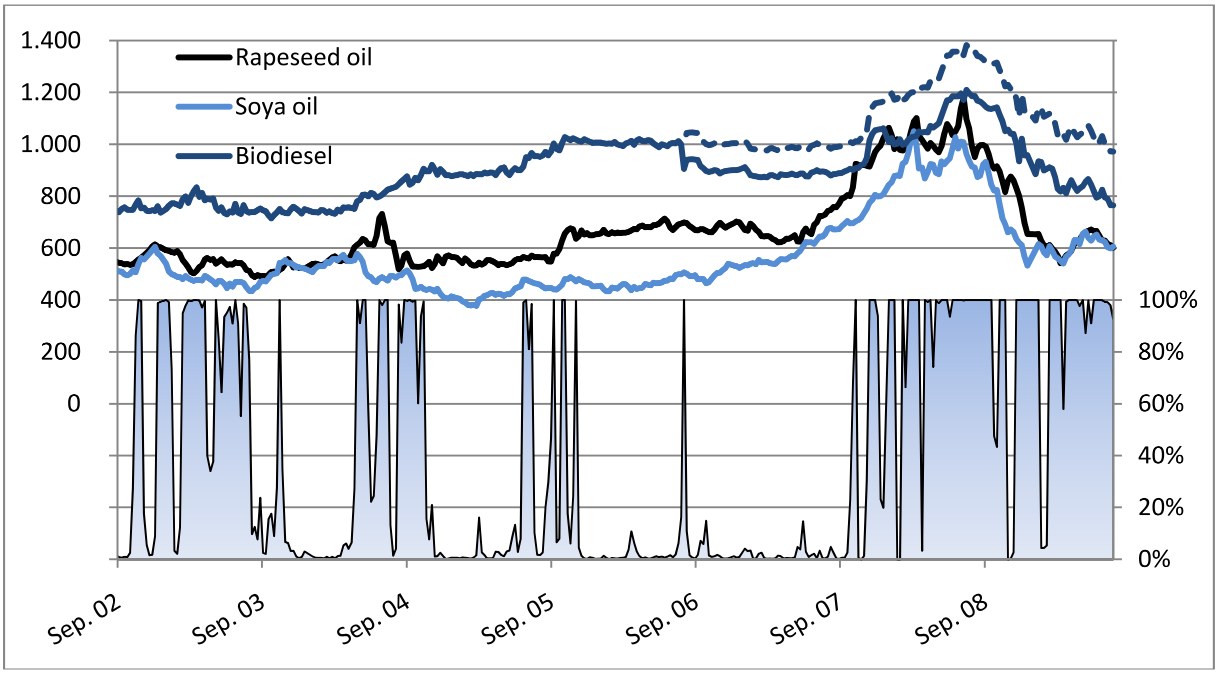
Source: Own calculations.
Note: Regime assignment according to highest probability.

The strong orientation to crude oil prices occurred temporarily in August 2006 when the tax was implemented. The "Strong adjustment" regime became more prevalent from late 2007 onwards. Different effects coincided which might have encouraged the stronger orientation towards crude oil prices. In the German market, the blending obligation was enforced for the first time in 2007. During 2007, the market for blends gained importance and sales in this segment reached the level of B100 sales. Furthermore, the import competition from subsidized US B99 increased substantially during the course of 2007. Consequently, large overcapacity arose in the German biodiesel industry and Germany faced the first decline in biodiesel sales. The effects seem to have contributed to a more crude oil oriented biodiesel price development, i.e. to the occurrence of the "Strong adjustment" regime.

In the relationship between biodiesel and the markets for rapeseed oil and soya oil, phases with the dominance of the one or the other regime are observed (Figure 8). The "Veg. Oil" regime was dominating until summer 2003 and in summer 2004 when the biodiesel market was rather small. The regime is indicated by a weak influence of biodiesel prices on vegetable oil prices. With the strong development of the biodiesel market from 2004 onwards, the market was dominated by the "Biodiesel" regime. Between late 2004 and the end of 2007, lagged price changes of biodiesel had a significant impact on changes in rapeseed oil prices. The rapeseed oil prices especially showed strong adjustment of disequilibria and significant short-run adjustment which indicates the importance of the biodiesel market. The regime even prevailed after the taxation of biodiesel in Germany in 2006 and the introduction of the blending mandate in 2007.

The "Veg. Oil" regime, which was increasingly observed from September 2007 on, dominated and was highly persistent in 2008 and 2009. This regime is indicated by slow disequilibrium responses (error-correction) of rapeseed oil prices and a strong reaction of rapeseed and soya oil prices to past changes of their own and each other's prices. This can be interpreted as a decrease in the importance of the biodiesel market for the vegetable oils and a stronger orientation of in particular rapeseed oil prices to the vegetable oil market. During this phase, different factors played an important role which will be addressed in detail below: the food crisis, subsidized US B99 exports and a strong overcapacity in biodiesel production.

Figure 8: Prices of biodiesel, soy oil, and rapeseed oil (left scale) and smoothed probabilities of the "Veg. oil" regime (right scale)



Source: Own calculations.

The 2007/08 food crisis was indicated by an overall increase in agricultural commodity prices. The rapeseed oil price peaked in summer 2008 at around 1,200 €/t. Even though the strong price increase made biodiesel production uncompetitive, the blending obligations still had to be met. The strong overcapacity in Germany was further aggravated by the increasing import pressure from US B99 imports. These developments led to a stronger influence of the crude oil market and stronger international integration of the formerly "national" biodiesel market. Furthermore, the role of rapeseed oil changed. Especially in the growth phase until

2006, rapeseed oil was almost exclusively used as the raw product for biodiesel production. The result can be seen in Figure 8, where a substantial gap between the prices for rapeseed oil and soya oil appeared in 2005. With the change in the market structure in 2006 and 2007 this price gap was diminishing but especially during the winter months, the predominant use of rapeseed oil is still unavoidable. However, we found that the price changes in the vegetable oil market gained importance for rapeseed oil price development, indicated by the "Veg. Oil" regime. Furthermore, a diminishing of the gap between soya and rapeseed oil prices can be observed especially in 2009. Hence, it has to be concluded that the biodiesel market decreased in its influence on the short-run rapeseed oil price behavior.

The strong import competition on the biodiesel market brought problems for the domestic processing industry. It also weakened the position of rapeseed oil on the EU market. Since the effects fall together with the food crisis and the blending obligations, the biodiesel industry was especially under pressure when rapeseed oil prices followed the overall price trends. The uncertainty in the industry is best reflected by the frequent changes in the price adjustment behavior in relation to crude oil prices in 2008 and 2009. The long-run equilibrium between biodiesel and crude oil appears to be constant. Hence, subsidized imports did not lower the biodiesel price. In the supply chain for biodiesel a much stronger impact of vegetable oil price changes for the development of rapeseed oil and soya oil prices is found. This indicates a weakening of the biodiesel industry and a strengthening of the food market. These effects can initially be caused by the scarcity of vegetable oil during the food crisis; however, their persistency beyond the high price phase mainly seems to be caused by strong import competition.

Conclusions

This article assesses vertical price relationships in the German biodiesel market with a focus on the link to energy markets on the one hand and to its raw products markets on the other. Weekly prices for crude oil, biodiesel, rapeseed oil and soya oil from 2002 to 2009 are analyzed. The period covers the rise of the biodiesel industry, strong changes in the biodiesel promotion framework, the food crisis and strong import competition from subsidized US B99. Stable long-run relationships between crude oil and biodiesel as well as between biodiesel, rapeseed oil and soya oil are found.

Even though the long-run equilibriums are stable, the price adjustment behaviors change in different phases of the market development. The Markov-switching Vector Error Correction Model detects latent regime in the data without the requirement of an *a priori* identification of the determinants or timings of the regime switches. Since the market development was influenced by several changes, this appears to be a very useful property. The fit of the model and the modeling results show the high suitability of this model under the observed market conditions. In the relationship between biodiesel and crude oil, three regimes with differing characteristics are found. The relationship between biodiesel, rapeseed oil and soya oil is best described by a two regime model.

The regimes in both relationships show similar characteristics with regard to their occurrence. While the phase of the strongest growth 2003 until 2007 is dominated by one regime, the previous periods as well as the phase from the end of 2007 until 2009 are dominated by the other regime(s) and frequent regime switches. This latter period is of interest since it shows a disturbance of the formerly continuously growing German biodiesel market. With the change in the legal framework for the promotion of biodiesel in 2006 and 2007, sales decreased for the first time in 2008 and strong overcapacity resulted. Furthermore, the B100 market began to disappear while the share of biodiesel used in blends increased. At the same time, the import competition from subsidized US B99 increased. The market was moreover disturbed by the overall increase in agricultural commodity prices in 2007/08 which also led to a sharp increase in rapeseed oil and soya oil prices.

In the relationship between biodiesel and crude oil, this phase is indicated by a much stronger influence of crude oil prices on biodiesel prices but also by frequent regime switches. This latter observation might reflect the uncertainty in the market, which was connected with the various factors discussed above. The stronger reaction to changes in crude oil prices indicates a stronger orientation to international markets. This might be primarily caused by the strong blending of biodiesel. However, the increasing imports of biodiesel have driven the EU biodiesel market from an insulated market to an internationally contested market.

These influences can also be found in relation between biodiesel, soya oil and rapeseed oil prices. During the food crisis, the international vegetable oil markets were found to play a more important role than the biodiesel market. This is indicated by the strong influence of past vegetable oil price changes and the missing reaction to past biodiesel price changes. The overall price increase in vegetable oil prices made biodiesel uncompetitive so that B100 sales decreased temporarily. On the blending market, domestic biodiesel had to compete with imported B99, putting further pressure on the prices. The rapeseed oil market lost its privileged position as an important source for biodiesel production and rapeseed oil prices oriented more to the vegetable oil market. While the subsidized US B99 imports certainly reflect a challenge for German biodiesel producers, they appear not to have a negative impact on the price developments and integration in the EU market. The link between biodiesel and crude oil prices was strengthened and rapeseed oil prices oriented stronger to soya oil price developments. However, the increasing uncertainty for the German biodiesel industry with these developments should not be neglected.

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