THE EFFECT OF BRAZILIAN CORN AND SOYBEAN CROP EXPANSION ON PRICE AND VOLATILITY TRANSMISSION

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ABSTRACT

This study aims to examine if the most recent changes in the Brazilian corn and soybean production have caused significant changes in prices and volatility transmission between Brazilian and U.S. markets. In addition to using econometric time-series methods tests to analyze price transmission among grain and oilseeds markets, we investigated the volatility spillover across U.S. and Brazil markets using causality in variance tests. Since structural break tests indicated the presence of one breakpoint, the sample was split in two periods: 1996-2006 and 2007-2014. Results suggest that the level of market integration has increased during the second period (2007-2014) with higher sensibility to price changes compared to the first period (1996-2006).

Keywords: corn, soybeans, price, volatility.

INTRODUCTION

Over the past decades, Brazil has largely expanded its soybean and corn production. Brazilian soybean production increased nearly six times since 1990, reaching 3.6 billion bushels in 2015. Meanwhile, the country's corn production increased nearly four times since 1990, reaching 3.3 billion bushels in 2015. The growth of Brazilian soybean production has occurred particularly in the Central-West region, and resulting from overall development of new biological, chemical, and mechanical technologies. On the other hand, the increase in corn production is mainly related to the growth of the winter corn crop, stimulated by the expansion of poultry and pork industries, as well as the use of early-maturing soybeans, which allow producers to plant corn directly after the soybean harvest (Mattos and Silveira, 2015).

The strong expansion of Brazilian production and exports, as well as changes in U.S. production, requires new research into futures and cash prices dynamics. A closer look into the changing production dynamics of these two large participants in the international corn and soybeans markets will provide insights into new trading strategies and price discovery, allowing the improvement of general risk management frameworks. Therefore, our main objective is to examine if the most recent changes in

Brazilian production have caused significant changes in prices and volatility transmission between the two countries.

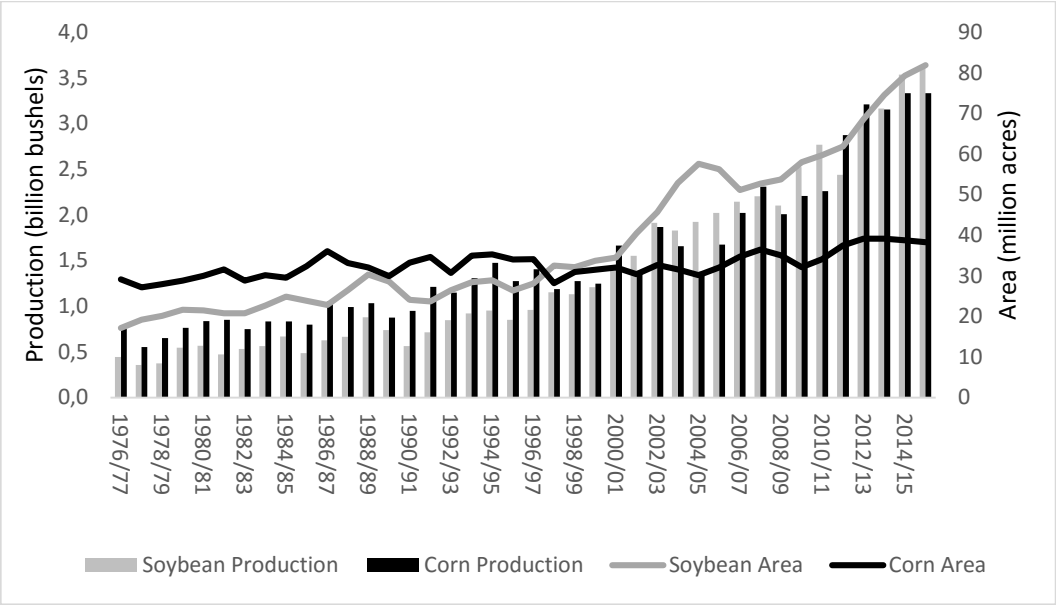
Several recent studies have already investigated the price and volatility transmission among grain and oilseeds markets (Ceballos et al., 2015; Hernandez, Ibarra and Trupkin, 2014; Liu and An, 2011; Balcombe, Bailey and Brooks, 2007; Kindie, Verbeke and Viaene, 2005; Yang, Zhang and Leatham, 2003). However, prior studies have been focusing on U.S. futures, and given less attention to the effects of the Brazilian cash and futures markets. Furthermore, only a few studies have investigated the dynamics of volatility across different countries, and specifically, the effect of the Brazilian market expansion on prices and volatility. According to Ceballos et al. (2015), understanding the sources of domestic commodity price volatility and the extension of volatility transmission between international and local markets is relevant to provide better global and regional policies to deal with high price volatility.

Our primary hypothesis is that the expansion of Brazilian corn and soybean production has affected Brazil-U.S. spot and futures price integration. The change in both countries' production improved the markets integration after 2010, when the expansion of the Brazilian second corn crop increased significantly. We understand that the price transmission and volatility dynamics across countries have changed. For corn, this change is more likely to have happened as a result of the increase of the winter crop, which is harvested in the second half of every (calendar) year. In addition, the majority of Brazilian exports are also concentrated between July and December. Consequently, we expect that second semester Brazilian cash and futures prices (e.g. September and November contracts) must be more integrated with CME Group futures, since Brazilian prices tend to respond more to factors that influence Brazilian exports, such as the U.S. crop, the USD-BRL exchange rate, and premiums between the U.S. and Brazil. Conversely, cash and futures prices related to the contracts that expire in the first semester (e.g. January, March, and May) tend to be more influenced by local supply and demand conditions in each country.

THE EXPANSION OF CORN AND SOYBEAN PRODUCTION IN BRAZIL

Between 1976 and 2015, Brazilian soybean production increased on average 5.5% per year, reaching 3.6 billion bushels in 2015/16 (Figure 1). In addition to this strong growth in the cropped area, technological advances have contributed to the expansion of productivity. While the planted area increased from around 17 million

acres to 82 million acres (compound annual growth rate - CAGR of 4.1%), productivity rose from 26 to around 44 bushels/acre (CAGR of 1.4%).



Source: Conab (Brazilian Food Supply Company) (2016)

Figure 1: Brazilian corn and soybean production and area between 1976/81 and 2015/16.

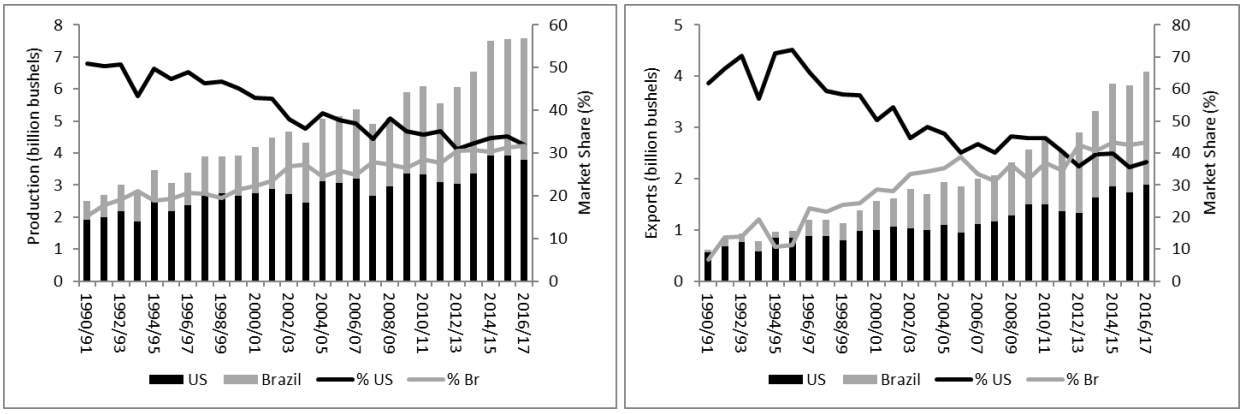
Figure 1 also shows the growth of Brazilian corn production, which increased from 758 million bushels in 1976/77 to 3.3 billion bushels in 2015/16 (CAGR of 4% during this period), suggesting that this expansion was explained mainly by productivity growth. Between 1970's and 2010's, productivity has risen from 26 to 87 bushels/acre, while planted area has reached 37 million acres, whereas in 1970's the total area was around 29 million acres.

The Brazilian soybean and corn production have expanded mostly in the Center-West area. While in the 1970's this region accounted for around 10% of Brazilian corn and soybean production, the share grew more than fourfold until 2015, reaching 43% for corn and 48% for soybeans. Goldsmith (2008, p. 780) summarized the reasons for the fast expansion of grain production in Brazil's Center-West region, pointing to the "availability of large tracts of arable land, soybean technology that produced yields equal to those of the United States, mechanization that allowed operational efficiency, and the lowest operating costs per hectare in the world".

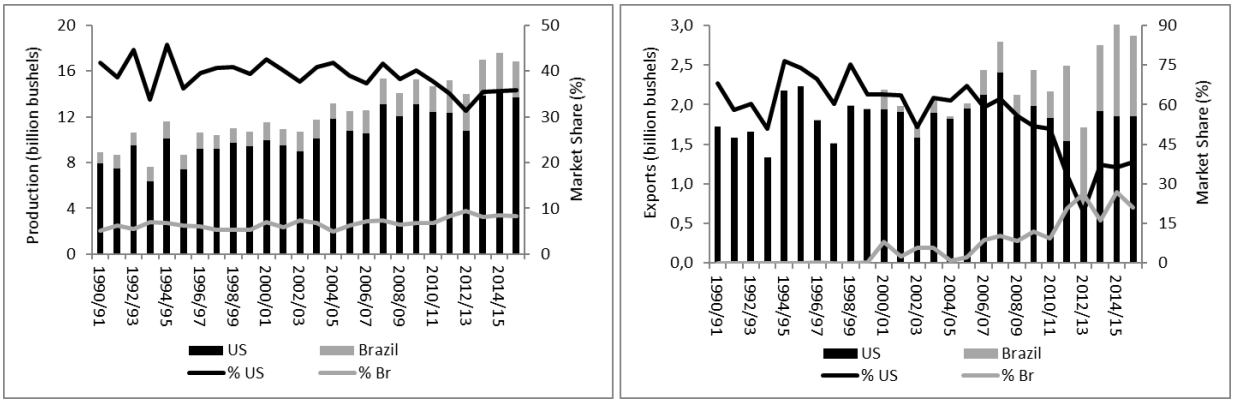
It is important to note that, with the expansion of soybean production, Brazilian farmers have adopted early maturing soybean, allowing the harvest during December-January. In addition to having a lower incidence of Asian soybean rust, a feature of this

period is the price premium for soybean exports. Furthermore, it became possible to grow the winter corn crop just after the soybean harvest, leading to the existence of two corn crops per year in Brazil (summer and winter crop)[1]. Nowadays, the winter crop share is around 60% of total production, whereas in the 1970's the share was close to zero (Silveira and Mattos, 2015).

As a result of the scenario previously described, Brazil has increased its importance in the world grain and oilseed market. For soybeans, the Brazilian share of global production (export) rose from 15% (7%) in 1990 to 30% (42%) in 2015, while U.S. share declined from 51% (62%) to 34% (36%) (Figure 2). If we include Argentina, both countries of South America are responsible, in the recent period, for 50% of the world production.



(a) Soybean production (b) Soybean Export



(c) Corn production (d) Corn Export

Source: USDA

Figure 2: Brazilian and U.S. corn and soybean production and export between 1990/91 and 2016/17.

[1] Most of the country, but Southern areas, have appropriate climate to have first and second crop.

Even though the Brazilian share of world corn production is only around 8%, the country's export share strongly increased from about zero to around 27% between 1990 and 2015. Conversely, the U.S. share of world corn production (export) has reached 36% (38%) of the country's total production in 2015, whereas in 1990 the share was around 42% (68%). The technology mix available in Brazil, which allows producers to have two corn crops in the same (crop) year, associated with the severe drought in the United States in the 2012/2013 season, together have promoted new opportunities to Brazilian producers in the corn international trade.

PREVIOUS RESEARCH

Several studies have recently explored price and volatility transmission among grains and oilseeds markets, considering two or more different regions. Price transmission and market integration issues were analyzed by different researchers across several markets and commodities, such as Booth and Ciner (1997) for corn; Booth, Brockman, and Tse (1998) and Goychuk and Meyers (2011) for wheat; Liu and An (2011) for soybean and cooper; Fossati, Lorenzo and Rodriguez (2009) for grains and beef.

Other studies examined the price and volatility transmission after the fast increase in agricultural commodities prices in 2008-2009, investigating if these relationships have been influencing agricultural markets in the short run or both short and long run (Beckmann and Czudaj, 2014; Gavennal, 2016). Many other studies applied traditional time series procedures to assess price and volatility transmission over different markets. Other studies also include in their analysis the integration over developed and emerging markets.

Yang et al. (2003) investigated the wheat futures prices and volatility transmissions among the main international producers (United States, Canada and European Union) over 1996-2002. The authors used the generalized forecast error variance decomposition and generalized impulse response analysis from a VECM estimation. Futures prices transmission estimations pointed out to a significant impact of U.S. market on Canadian market, while E.U. is self-dependent and not affect by any market. However, their findings for the volatility transmission analysis were in an opposite direction, with the Canadian market affecting the U.S., and the EU affecting both the U.S. and Canada.

Concerned with threshold effects in price transmission in the Brazilian, Argentinean and U.S. grain markets (soybean, corn and wheat), Balcombe et al. (2007) introduced a generalization on existing threshold models in which the prices could be attracted to either the edge of threshold interval or within interval, covering the Eq-TAR and Band-TAR models with a Bayesian approach to the estimate the models. Their results indicate that the existence of threshold effects over price transmission depends of each crop/market, with largest effect on corn prices and from the U.S. and Argentina markets rather from Brazil.

Hernandez et al. (2014) examined the level of interdependence and volatility transmission in global agricultural futures markets, assessing their estimations in major agricultural futures exchange in the USA, Europe and Asia for the most negotiated futures contracts as soybean, corn and wheat from 2004 to 2009. The authors estimated a MGARCH model with T-BEKK, full T-BEKK, CCC and DCC specifications. General results suggest the existence of strong own- and cross-volatility spillovers and dependence between the most exchanges, especially from Chicago through other exchanges. In addition, they found out that the level of interdependence across exchanges has not increased in the past years.

Ceballos et al. (2015) estimated grain price and volatility transmission from global to domestic developing markets focusing on the effects of international prices of corn, wheat, rice and sorghum on 41 domestic prices of grains in Africa, Asia and Latin America, from 2000 through 2013. The estimation was based on a multivariated generalized auto-regressive conditional heteroskedasticity (MGARCH) model using the the Engle and Kroner proposed BEKK specification. Overall, results suggest lead-lag relationship from world to local prices in few cases. However, many interactions across these markets were found in terms of volatility transmission, pointing out to stronger volatility influencing wheat and rice markets, especially because their large share traded in international market. The study also showed that volatility has less influence over sorghum and corn markets.

RESEARCH METHOD

The empirical analysis of this work is conducted in three steps. The first step consists on the evaluation of structural breaks in each price series. The second step consists on the analysis of market integration between the Brazilian and the U.S.

markets. Finally, the third step explores the volatility transmission among futures and spot markets in both countries.

Structural break analysis and unit root tests

In order to test for breakpoints in the price series, we conducted two different groups of tests: structural change and unit root tests.

Zeileis et al. (2003) developed a practical simple test to identify an unknown date of break in a time series. The authors considered a standard linear model, such as:

$$y_i = x_i^T \beta_j + u_i \qquad (i = i_{j-1} + 1, \dots\ i_j \quad j = 1, \dots, m+1) \tag{1}$$

The test consists in estimating consecutive regressions using m+1 segments of size $I_{m,n} = \{i_1, \dots, i_m\}$, starting with $i_0 = 0$ until $i_{m+1} = n$. The vector x_i is a k x 1 vector of ones, which allows to test for changes in the mean of the dependent variable, y_i. The null hypothesis to be tested is $H_0: \beta_i = \beta_0$ (i = 1,…, n) against the alternative that at least one coefficient varies over time. An alternative specification can also be used to test for changes in the trend, or trend breaks, when x_i contains a sequence of increasing values, such as t = 0, 1, …, T.

The residuals (u_i) estimated via Ordinary Least Squares (OLS) are used in the traditional F statistics (Chow) test to verify the alternative hypothesis of a single change in the level of the variable y_i at an unknown time. The authors use segments (partitions) of the data sample to calculate a sequence of F statistics (one for each subsample) and the null hypothesis can be rejected according to the supremum value of the test statistics.

In addition to a structural break test, we also conducted a unit root test that account for shifts in the level of the price variables. The unit root test can be helpful in identifying possible breakpoints in the series, but it is also a necessary procedure when modeling time series. Different authors, as Enders (2015) and Pindyck and Rubinfeld (1998) have already listed problems caused by the use of non-stationary variables in standard regression models. In order to avoid spurious regression estimates, (non)stationarity tests are conducted to find if a series contains one unit root. Traditional tests as the Augumented Dickey-Fuller (ADF) and the Phillips-Perron (PP) are usually implemented in this case. However, traditional tests fail to reject the unit root hypothesis when the data generating process is that of stationary fluctuations around a trend function which contains a one-time break, for instance (Perron, 1989).

Zivot and Andrews (1992) developed a unit root test (ZA test) which treats a possible breakpoint as endogenous, i.e., they allow a breakpoint to be estimated rather than fixed. The null hypothesis tested is that a given series $\{y_t\}_1^T$ has a unit root with a drift, and that an exogenous break occurs at time $1 < T_B < T$. The alternative hypothesis is that $\{y_t\}_1^T$ is stationary about a time trend and an exogenous change occurs in the trend at time T_B. The authors used three different models and according to the specification adopted, the null hypothesis can be changed to test for a change in the intercept (Model A), in the slope of the trend function (Model B), or both (Model C). This specification follows the previous work developed by Perron (1989) who labeled models A, B and C respectively as "crash", "changing growth" and "combo".

Such as in Perron (1989), Zivot and Andrews (1992) use a modified Augmented Dickey-Fuller (ADF) equation which includes dummy variables in the three aforementioned models to test for a unit root. The rule to determine the breakpoint is to find the minimum t statistics after estimating modified ADF regressions with different break fractions of length T_B/T.

Market integration procedures

We use traditional time series approaches to identify market integration between spot and future markets in Brazil and in the US. We use cointegration tests to identify the presence of a long-run relationship among prices (integration) and the vector error correction model (VECM) to verify how prices adjust from deviations to the equilibrium in the short run.

If all the price variables in the model are non-stationary with the same integration order, we test the existence of long-run relationship among prices using the well-known Johansen multivariate test. If we find at least one cointegration relationship, we can assume the different markets are integrated. The number of cointegration relationships can be determined after estimating the model in equation (2):

$$\Delta P_t = A_0 + \Pi P_{t-1} + \sum_{i=1}^{k-1} \Pi_i \Delta P_{t-i} + \varepsilon_t \qquad (2)$$

Where A_0 is a vector containing the intercept, and ΔP_t is a ($n \times 1$) vector of the first difference of prices. The ($n \times n$) matrix Π, can be written as $\Pi = \alpha\beta'$ where α and β are ($n \times r$) matrices containing the speed of adjustment parameters and the cointegrating vectors, respectively. The matrix Π_i contains all the parameters estimated

to represent the impact of lagged variables in the system, and ε_t is a vector of random error terms (Lutkepohl, 2006).

According to Enders (2004) when the model presented in (2) is estimated using maximum likelihood, the rank of Π is determined. Two different test statistics (trace and eigenvalue) are used to test the null hypothesis of rank Π = 0. If the null cannot be rejected, the prices are not cointegrated and there is no integration among the markets. On the other hand, if the null hypothesis is rejected, a sequential test is conducted to determine the number of cointegrating relationships.

Once we find the markets to be integrated, we can use the matrix Π to investigate the long-run dynamics of prices, and how they adjust to deviations towards the equilibrium. The Vector Error Corretion Model (VECM) then can be used since it not only allows estimating the adjustment back to the equilibrium, but it also allows to test for Granger causality, and to determine the impact of shocks to different prices using impulse response functions.

We implement Granger causality tests using bivariate vector autoregressions to determine if lagged information on a certain price set provides any statistically significant information about a second price set. If not, the first price set does not Granger-cause the second. Once we have the results of all pairwise causality tests, we can have a better understand of how the different spot and futures markets in Brazil and the US are related. Therefore, these results can help building a more appropriate sequence of shocks when implementing the impulse response functions.

If we find statistical evidence of a structural break in the dataset, the role sequence of tests described above needs to be implemented before and after the breakpoint. This type of comparison can give us a better knowledge of how the corn and soybeans markets are integrated in both countries, and how these markets are related in the long and short-run. We also included a dummy variable during the months of June to September in each year of the analysis to represent the harvest of the Brazilian winter crop.

Volatility transmission methods

In order to explore causal relations related to price changes between Brazilian and U.S. markets, we use a causality in variance test formulated by Cheung and Ng (1996). After the estimation of a GARCH(1,1) model, we obtain the series of squared standardized residuals and calculate the cross correlation function (CCF) of these series.

With the CCF, we test the null hypothesis of no causality-in-variance at a specific lag *k*, using the standard normal distribution

DATA

The dataset consists of daily futures and spot prices for corn and soybeans between November 1996 and December 2014. Futures prices represent closing quotes for corn and soybean nearby contracts from CME Group and BMF&FBOVESPA. The spot price analysis considers only the main producing areas in Brazil (Center-West) and the U.S. (Midwest).

Table 1 shows the descriptive statistics and correlations for spot and futures prices. Average corn prices are between the $3.0-$4.1/bushel range, while average soybean prices are in the $7.0-$8.6/bushel range. We also can verify a smaller volatility for corn and soybeans in Brazilian spot markets when compared to all other markets in Brazil and in the US. In addition, the correlations are, in general, very high for both commodities and markets, with smaller values between the Brazilian and the US corn prices.

Table 1: Descriptive statistics and correlations for Brazilian and U.S. spot and futures markets for corn and soybeans [(a)] (November 1996 - December 2014).

Markets	Summary statistics					Correlations			
	Mean	Med	Max	Min	SD	BRCF	BRCS	USCF	USCS
Corn markets									
Futures price (BRCF)	4.05	3.43	8.65	1.49	1.64	1.0000	0.9783	0.9016	0.8845
Spot price (BRCS)	3.05	2.60	6.60	1.25	1.25		1.0000	0.9012	0.8834
Futures price (USCF)	3.52	2.74	8.31	1.75	1.69			1.0000	0.9952
Spot price (USCS)	3.56	2.81	8.65	1.62	1.74				1.0000
Soybean markets						BRSF	BRSS	USSF	USSS
Futures price (BRSF)	8.60	7.08	20.16	3.86	3.74	1.0000	0.9874	0.9834	0.9817
Spot price (BRSS)	7.01	5.98	16.53	2.92	3.15		1.0000	0.9782	0.9764
Futures price (USSF)	8.57	7.37	17.71	4.10	3.55			1.0000	0.9974
Spot price (USSS)	8.43	7.17	17.90	3.88	3.58				1.0000

Source: Commodity Resource Bureau, BM&FBOVESPA, and Agência Estado
[(a)] Grain prices in U.S. and Brazil are expressed in US$/bushel.
Note: *n* = 4,226 observations.

RESULTS

Table 2 reports the results for the structural break and unit root tests. We adopted the structural break test specification which tests the null hypothesis of no break in the level (intercept) of the price variables. The ZA unit root test was also implemented using the level shift specification (crash model).

The test results indicate the presence of one breakpoint (rejection of the null hypothesis for the Zeiles et al. (2003) test) in all variables. The null hypothesis of non-stationarity could not be rejected for any price series, indicating that all the series have a unit root with a drift.

Table 2: Structural break and unit root test results

Test	Zeiles et al. (2003)		Zivot and Andrews (1992)	
Series	Sup. F	Date of break	min(t stat)	Date of break
Corn markets				
Futures price (BRCF)	9145.7***	07-13-2007	-3.847NS	07-26-2006
Spot price (BRCS)	7407.6***	10-03-2006	-3.821NS	09-26-2006
Futures price (USCF)	8339.7***	11-05-2007	-3.223NS	09-15-2006
Spot price (USCS)	8224.3***	11-07-2007	-3.152NS	09-13-2006
Soybean markets				
Futures price (BRSF)	18866***	08-16-2007	-3.861NS	05-09-2007
Spot price (BRSS)	17201***	08-27-2007	-3.936NS	08-17-2007
Futures price (USSF)	14278***	08-28-2007	-3.858NS	04-26-2007
Spot price (USSS)	13906***	09-26-2007	-4.025NS	08-17-2007

***significant at 1%, NS = not significant

Since the estimated dates of break were different between the two tests and among the series, we decide to split our analysis in two periods: i) the first period starts in the beginning of our sample and ends before the first break was found (07-26-2006), consisting of 2,283 daily observations; ii) the second period starts after the last break was found (09-26-2007), consisting of 1,627 daily observations.

The Johansen cointegration test could then be used, since all the price series were found to be I(1) process. For both periods the results of the cointegration tests detected the presence of multiple cointegrating relations in the model that includes an intercept and no trend in the cointegration equation. We found three relations for the first period, and four for the second, according to the maximum eigenvalue tests[2]. The

[2] The trace test statistics indicated the presence of four and five cointegrating relations for the first and second period, respectively.

results confirm the initial hypothesis of market integration between the two countries and among all the corn and soybeans markets we analyzed.

Since we are only interested in understanding how the market integration evolved from the first to the second period, we used the results of the Granger causality tests to ordinate the variables according to their causality relationships before we used the VECM to estimate one cointegrating relation for each period[3]. The results for the Granger causality tests are shown in Figure 1A, in the Appendix. The top and bottom parts of the figure can be compared to check the number and directions of all statistically significant causality relations in the Granger sense between all pair of variables. It is clear that during the second period more causality relations were found to be significant than in the previous period. This result may suggest that the markets were more integrated after 2007, than they were before 2006.

In order to facilitate our comparisons between the estimations for the two periods, the cointegration vectors were normalized and ordered according to the most endogenous variables for the first period. We present the cointegrating relationships as well as the speed of adjustment parameters, and the dummy variables representing the winter crop harvest in Brazil, in Table 3[4].

Table 3: VECM results for the 1st and 2nd period

First period				Second period			
Variable	Long run	Short run	Dummy	Variable	Long run	Short run	Dummy
USSS	1.000	-0.143***	-0.006*	USSS	1.000	-0.046**	-0.019*
BRSS	-0.004^{NS}	-0.037***	0.010***	BRSS	-0.174***	-0.027**	0.008^{NS}
BRSF	0.039**	0.032*	0.008**	BRSF	0.291***	-0.085***	0.026**
BRCF	0.095***	-0.021^{NS}	0.000^{NS}	BRCF	0.403***	-0.016*	0.008^{NS}
USSF	-1.064***	0.154***	-0.018***	USSF	-1.131***	0.087***	-0.039***
BRCS	-0.079***	0.015*	0.000^{NS}	BRCS	-0.312***	0.021***	-0.006*
USCS	-0.867***	0.012^{NS}	-0.005***	USCS	-0.360***	0.009^{NS}	-0.008^{NS}
USCF	1.009***	-0.011^{NS}	-0.002*	USCF	0.263*	-0.006^{NS}	-0.008^{NS}
Intercept	-0.115	Lags: 9		Intercept	-0.570	Lags: 7	

*** significant at 1%, ** significant at 5%, * significant at 10%, NS = not significant

USCF = US corn futures prices; USSF = US soybeans futures prices; BRCF = Brazilian corn futures prices; BRSF = Brazilian soybeans futures prices; USCS = US corn spot prices; USSS = US soybeans spot prices; BRCS = Brazilian corn spot prices; BRSS = Brazilian soybeans spot prices

[3] We used the results of the Granger causality tests to determine an order to estimate a single cointegrating relationship since we did not assume any previous ordering for the integration relations among the different markets.

[4] Lags were included in the estimations in order to correct for residual autocorrelation problems. LM tests indicate the null hypothesis of no autocorrelation could no longer be rejected after the introduction of the correspondent number of lags in each equation.

According to Table 3, we observe that the way the variables are related in the long and short run did not change very much since most of the parameters kept the same signal in the two periods. However, it is possible to identify that the magnitude of the parameters values changed significantly for most of the variables, especially in the cointegrating vector (long run). This result can indicate that the markets became more integrated during the second period and are now more sensitive to price changes than they were before.

We can analyze the speed to each market adjusts to short run deviations towards the equilibrium observing the values of the "short run" parameters. If a certain market does not adjust or takes too long to adjust towards the long run equilibrium after a shock for instance, there may be opportunities for arbitrage between the two markets. When we observe the results in Table 3, we can conclude that most of the speed of adjustment parameters were significantly different from zero in both periods. For this reason we can conclude that, if disequilibrium occurs, most of the markets are able to correct the deviations back towards the long run path. However, most of the short run parameters were found to be smaller in the second period, which indicates the speed of adjustment seems to have slowed down in most markets after the breakpoint.

The second corn crop seems to have caused just a modest direct impact in the prices of just a few markets in Brazil and in the US.

We also used impulse and response (IR) functions to verify how different variables respond to shocks in the Brazilian corn and soybean spot prices. We were mainly interested in verifying how the US futures and spot market reacted to shocks in those variables before and after the breakpoint. The results obtained from the IR analysis are shown in Figure 4.

The results presented in Figure 4 were estimated after imposing the recursive ordering (Cholesky decomposition) obtained after the results of the Granger causality tests for each period[5]. According to Enders (2015) "the decomposition forces a potentially important asymmetry on the system" since a shock in the most exogenous variable has contemporaneous effects on the others.

[5] The ordering for the first period was: USCF, USCS, BRCS, USSF, BRCF, BRSF, BRSS, USSS. And for the second period: USCS, USCF, USSS, BRSS, BRCS, BRCF.

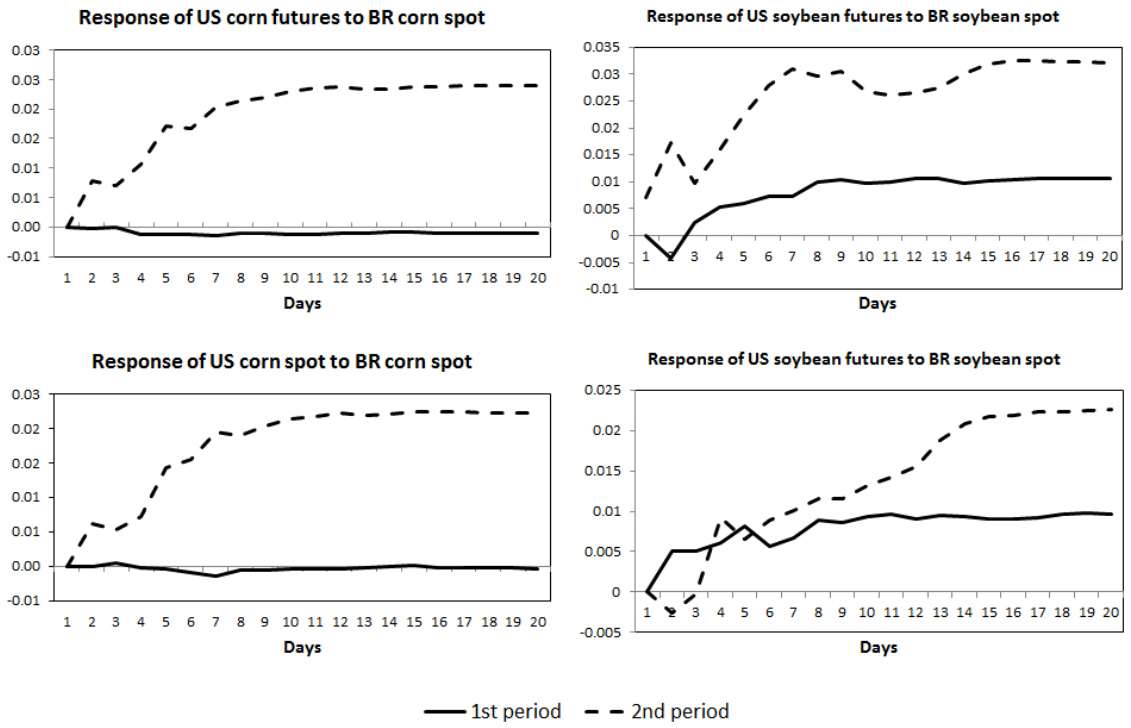


Figure 4: Change in different variables to one standard-deviation shock in Brazilian prices during the first and second periods

The impulse response results were significantly different between the two periods and between the two commodities. During the first period, shocks in the corn spot prices were not significantly responded in neither the US corn futures or spot markets. The responses to those shocks in the US markets were quite small and died out not before too long. During the second period, on the other hand, contemporaneous shocks in the Brazilian corn prices were responded by higher (although still small) changes in the US corn markets. Similar changes also happened in the soybean futures and spot markets in the US. These results show that the Brazilian corn and soybean spot markets became more relevant in explaining changes in the US markets after 2007.

At last, the causality in variance results indicate that there was, in general, no causality in variance between Brazilian and the US corn prices during the first period (1996-2006). Conversely, during the second period, the US corn markets contributed to the destabilization of Brazilian prices (Table 4). For soybean markets, results suggest, in general, that the US markets contribute to the destabilization of Brazilian prices during both periods (Table 5).

Table 4: Causality in variance tests for corn markets

Lag k	BR Futures-US Futures 1996-2006	BR Futures-US Futures 2007-2014	BR Spot-US Spot 1996-2006	BR Spot-US Spot 2007-2014	BR Spot-US Futures 1996-2006	BR Spot-US Futures 2007-2014	BR Futures-US Spot 1996-2006	BR Futures-US Spot 2007-2014
	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$
-5	-0,0063	0,0156	-0,0251	-0,0084	-0,0014	-0,0158	-0,0211	0,0128
-4	0,0113	-0,0044	-0,0117	0,0286	0,0000	0,0328 ***	0,0156	0,0039
-3	0,0077	0,0159	-0,0125	0,0210	-0,0364	0,0497 **	0,0287 ***	0,0011
-2	0,0198	0,0055	0,0134	-0,0229	0,0052	-0,0191	0,0181	-0,0092
-1	-0,0267	0,0063	-0,0047	0,0353 ***	-0,0026	0,0569 **	-0,0281	0,0034
0	0,0281 ***	0,2852 *	0,0339 **	0,1643 *	0,0289 ***	0,1324 *	0,0349 **	0,2812 *
1	-0,0297	0,0660 *	0,0225	0,0495 **	-0,0045	0,0727 *	-0,0222	0,0577 *
2	0,0531 *	0,0418 **	0,0115	0,0646 *	0,0231	0,0402 ***	0,0307 ***	0,0400 ***
3	0,0082	0,0259	0,0417 **	0,0421 **	0,0307 ***	0,0430 **	0,0084	0,0353 ***
4	0,0392 **	0,0142	-0,0025	0,0705 *	0,0185	0,0629 *	0,0150	0,0071
5	0,0234	0,1355 *	0,0011	0,0955 *	-0,0067	0,1080 *	0,0174	0,1095 *

Notes: *, ** and *** denote significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Causality in variance tests for soybean markets

Lag k	BR Futures-US Futures 1996-2006	BR Futures-US Futures 2007-2014	BR Spot-US Spot 1996-2006	BR Spot-US Spot 2007-2014	BR Spot-US Futures 1996-2006	BR Spot-US Futures 2007-2014	BR Futures-US Spot 1996-2006	BR Futures-US Spot 2007-2014
	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$	$r_{uv}(k)$
-5	-0,0355	0,0289	-0,0277	-0,0007	-0,0037	0,0274	0,0107	0,0055
-4	-0,0068	-0,0095	0,0119	0,0005	-0,0224	0,0154	-0,0168	0,0322 ***
-3	0,0076	0,0136	0,0069	0,0608 *	-0,0019	0,0065	-0,0273	0,0206
-2	-0,0215	0,0032	-0,0069	-0,0055	0,0249	0,0051	-0,0090	0,0053
-1	0,0231	0,4819 *	0,0571 *	0,0053	-0,0247	0,3703 *	0,1186 *	0,0221
0	0,3257 *	0,1783 *	0,1498 *	0,4219 *	0,1457 *	0,2711 *	0,2603 *	0,5715 *
1	0,0041	-0,0318	0,0301 ***	0,0053	0,0176	0,0503 **	0,0028	0,0149
2	0,0083	0,0202	0,0463 **	0,0485 **	0,0780 *	0,0041	-0,0121	0,0166
3	0,0319 ***	-0,0074	0,1040 *	0,0480 **	0,0887 *	0,0347 ***	0,0269 ***	0,0378 ***
4	0,0927 *	0,0606 *	0,0959 *	0,0809 *	0,1029 *	0,0255	0,0734 *	0,0608 *
5	0,1129 *	0,0244	0,1248 *	0,2408 *	0,1812 *	0,0842 *	0,0974 *	0,1189 *

Notes: *, ** and *** denote significance at the 1%, 5%, and 10% levels, respectively.

CONCLUSIONS

This research explored price and volatility transmission across corn and soybean markets between 1996 and 2014 in two countries, Brazil and the U.S.

Our findings show evidence of a structural break in 2007, which can be explained by some relevant factors: the end of the first commodity price boom (Figure 1A), expansion of the demand for corn-based ethanol as a fuel additive and alternate

fuel in the U.S., and great growth of the winter corn crop in Brazil (Figure 2A). Consequently, two separated periods were analyzed (1996-2007 and 2008-2014).

The main results suggested that the price relationships between Brazilian and the U.S. markets have changed as the corn and soybean futures and spot markets became more integrated after 2007. We also found that in the most recent period the US prices responses to variations in the Brazilian spot markets have increased significantly. In addition, the analysis of volatility spillovers show that the US markets have contributed to the destabilization of Brazilian prices in both periods.

REFERENCES

Balcombe, K, A. Bailey, J. Brooks (2007). Threshold effects in price transmission: the case of Brazilian wheat, maize, and soya prices. *American Journal of Agricultural Economics* 89, 308-323.

Beckmann, J., R. Czudaj (2014). Volatility transmission in agricultural futures markets. *Economic Modelling*, 36, 541-546.

Booth, G. G. and C. Ciner (1997). International transmission on information in corn futures markets. *Journal of Multinational Financial Management*, 7, 175-187.

Booth, G. G., P. Brockman, and Y. Tse (1998). The relationship between US and Canadian wheat futures. *Applied Financial Economics*, 8, 73-80.

Ceballos, F.; M. A. Hernandez, N. Minot, M. Robles (2015). Grain price and volatility transmission from international to domestic markets in developing countries. *Proceedings of the AAEA & WAEA Annual Meeting*, San Francisco, California.

Cheung, Y-W, L.K. Ng (1996). A causality in variance test and its application to financial market prices. *Journal of Econometrics*, 72, 33-48.

Enders, W. (2015). *Applied Econometric Time Series*. New York: Wiley.

Fossati, S., F. Lorenzo, and C. M. Rodriguez (2007). Regional and international market integration of a small open economy. *Journal of Applied Economics*, 10, 77-98.

Ganneval, S. (2016). Spatial price transmission on agricultural commodity markets under different volatility regimes. *Economic Modelling*, 52, 173-185.

Goldsmith, P. (2008). Soybean production and processing in Brazil. In: *Soybeans: chemistry, production, processing and utilization*. Edited by Johnson, L. A.; White, P. J. and Galloway. Elsevier Inc., 773-798.

Goychuk, K. and W. H. Meyers (2011). Black sea wheat market integration with the international wheat markets: some evidence from co-integration analysis. *Proceedings*

of Agricultural and Applied Economics Association Annual Meeting, July 24-26, 2011, Pittsburgh, Pennsylvania.

Hernandez, M. A., R. Ibarra, D. R. Trupkin (2014). How far do shocks move across borders? Examining volatility transmission in major agricultural futures markets. *European Review of Agricultural Economics*, 41, 301-325.

Kindie, G., W. Verbeke, J. Viaene (2005). Modeling spatial price transmission in the grain markets of Ethiopia with an application of ARDL approach to white teff. *Agricultural Economics*, 33, 491-502.

Liu, Q. and Y, An (2011). Information transmission in informationally linked markets: Evidence from US and Chinese commodity futures markets. *Journal of International Money and Finance*, 30, 778-795

Liu, Q., Y. An (2011). Information transmission in informationally linked markets: Evidence from US and Chinese commodity futures markets. *Journal of International Money and Finance*, 30, 778-795.

Lütkepohl, Helmut. (2006). *New introduction to multiple time series analysis*. Berlin: Springer.

Mattos, F. L., and R. L. F. Silveira (2015). The effects of Brazilian second (winter) corn crop on prices seasonality, basis behavior and integration to international market. Proceedings of the NCR-134 *Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management*. St. Louis, MO.

Perron, P. (1989). The grat crash, the oil price shock and the unit root hypothesis. *Econometrica*, 57, 1361-1401.

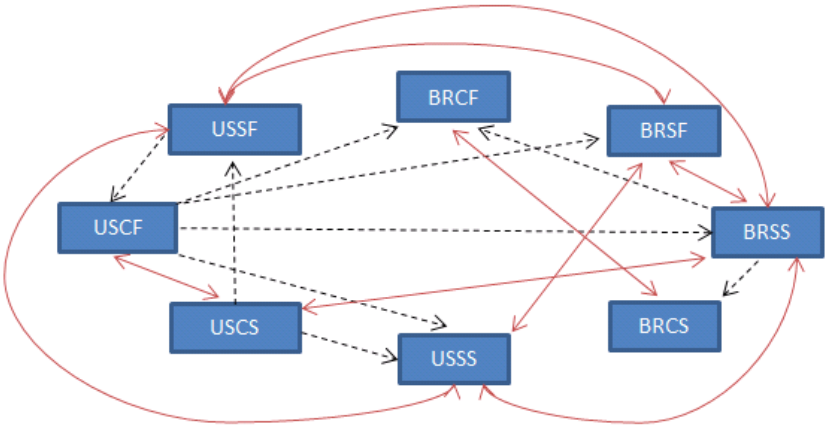
Pindyck, R. S. R., Rubinfelf. D. L. (1998). *Econometric models and economic forecast*. Boston: Irwin/McGraw-Hill.

Yang, J., J. Zhang, D. J. Leatham (2003). Price and volatility transmission in international wheat futures markets. *Annals of Economics and Finance*, 4, 37-50.

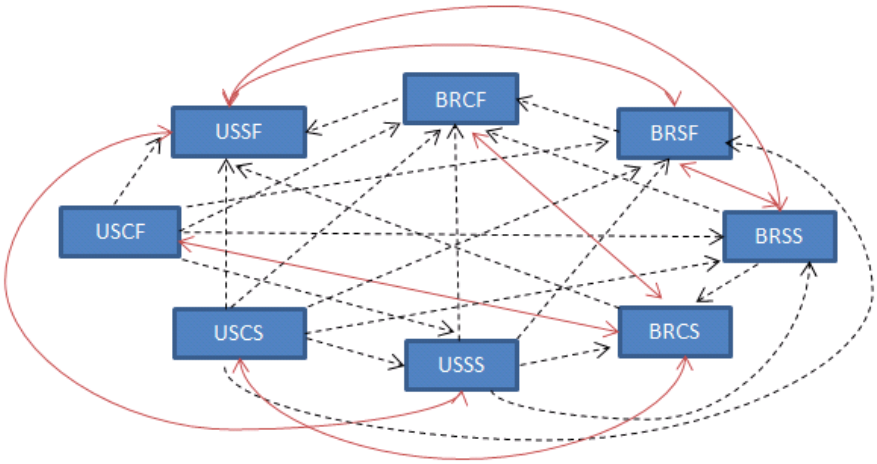
Zeileis A., Kleiber C., Krämer W., Hornik K. (2003), Testing and Dating of Structural Changes in Practice, *Computational Statistics and Data Analysis*, 44, 109-123.

Zivot. E, Andrews, D. W. K. (1992). Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *Journal of Business & Economic Statistics*, Vol. 10, No. 3. 251-270.

Appendix



Granger causality diagram for the first period*



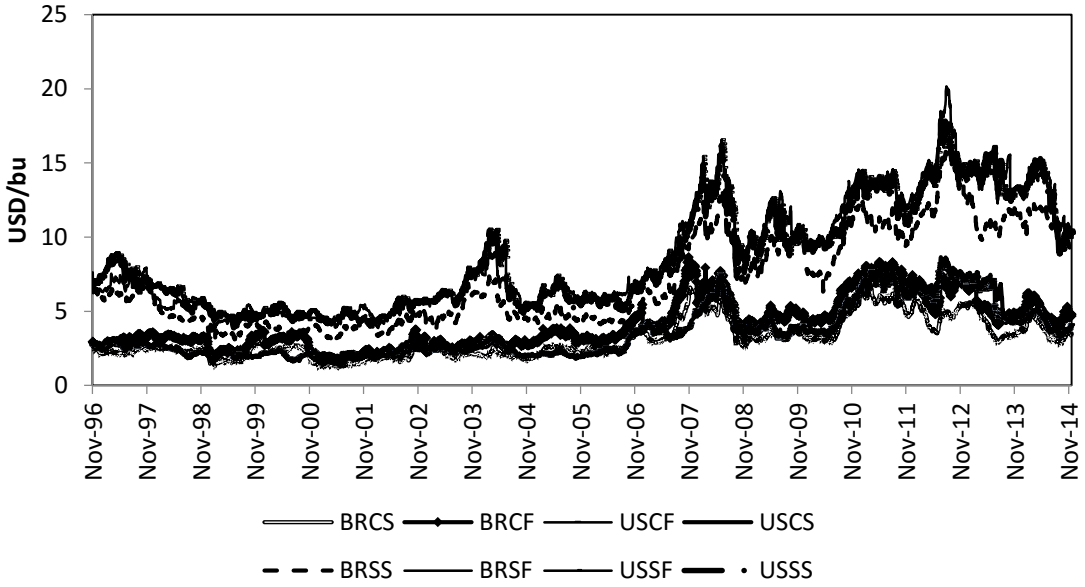
Granger causality diagram for the second period*

Legend: solid lines indicate bidirectional causality while dashed lines indicate unidirectional causality

USCF = US corn futures prices; USSF = US soybeans futures prices; BRCF = Brazilian corn futures prices; BRSF = Brazilian soybeans futures prices; USCS = US corn spot prices; USSS = US soybeans spot prices; BRCS = Brazilian corn spot prices; BRSS = Brazilian soybeans spot prices.

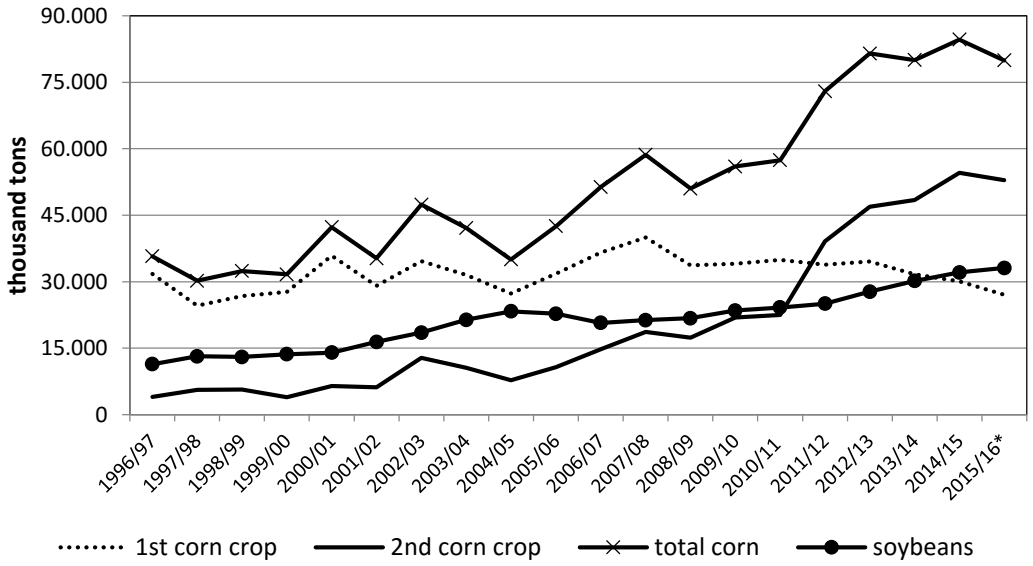
* all listed relations are significant at 5%

Figure 1A: Granger causality diagrams for corn and soybeans price series before and after estimated breakpoints



Source: Commodity Resource Bureau, BM&FBOVESPA, and Agência Estado

Figure 2A: Spot and futures corn and soybean prices in Brazil and in the US.



Source: Conab (2016)

Figure 3A: Brazilian soybeans, 1st, 2nd and total corn production (* forecast)