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Núm. 1009
2017



tá - Colombia - Bogotá - Col



Uncovering the time-varying nature of causality between oil prices and stock market returns: A multi-country study¹

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¹*Disclaimer:* The views expressed in the paper are those of the authors and do not represent those of the Banco de la Republica or its Board of Directors.

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Abstract

We study the relation between oil prices and stock market returns for a set of six countries, including important oil consumers and demanders. We study interconnectedness between oil and stock markets and characterize the dynamics of transmission and reception between them. We test for Granger causality between markets dynamically, endogenously identifying periods for which oil prices have responded to innovations in financial markets. Our results on connectedness show that the direction of transmission is mainly from stock markets to crude petroleum prices. Additionally, connectedness increased importantly around the global financial crisis, and reports high levels until 2014. Regarding causality, we find evidence of bidirectional relations between stock market returns and crude petroleum prices. Causality is stronger during times of financial volatility as well. Our results have important implications both for investors and policy makers.

JEL Classification:G01; G12; C22.

Keywords: *Time-varying causality; Oil price; Stock market returns; Emerging market economies.*

1 Introduction

The relation between oil prices and stock market returns has recently regained interest in both academic and policy circles. The aftermath of the recent international financial crisis has witnessed the surge of unprecedented sharp movements in oil and stock prices, motivating studies on causes, consequences and dynamics of this behavior. Volatility of oil and financial markets have important effects on macroeconomic stability, specially for emerging markets that are important producers and consumers of crude oil and its derivatives. Understanding the dynamic linkages between oil and stock prices is therefore important both for investors and policy makers.

While the vast majority of studies assume that oil prices are exogenous and test the effect of oil price shocks on stock returns, a new strand of the literature that does not take this supposition for granted is emerging. Particularly, papers on the financialization of oil markets argue that changes in the conditions of traditional financial markets affect commodity markets leading to impacts on spot commodity prices. For instance, Turhan et al. (2014) show that in recent years oil prices have been determined not only by aggregate supply and demand, but also by investment preferences and investors' behavior. This finding has been supported by other studies that have encountered bidirectional causality between oil prices and stock market returns, specially during periods of financial distress (Lee et al., 2012; Ding et al., 2016; and, Zhang, 2017).

In this paper we study the relation between oil prices and stock market returns for a set of six countries. Our contributions to the literature are three-folded. First, we uncover the dynamic multivariate relation between oil prices and stock market returns and measure connectiveness from a global perspective. Concretely, we compute both total and directional connectedness indicators (statically and dynamically) using forecast error variance decomposition from vector autoregressions, following the method proposed by Diebold and Yilmaz (2012, 2014). To the best of our knowledge, this is the second paper in this literature that follows this approach. Second, we are the first study to implement this approach for a set of

countries including both developed and emerging economies, all of them being major participants in oil markets.¹ And, third, we study causality between oil prices and stock market returns, following the recently developed method proposed by Hurn et al. (2016). Using this method we are able to study endogenous changes in causality over time, with the advantage of admitting bidirectional relationships. Our results on connectiveness show that oil shocks do not affect financial markets as importantly as it is frequently assumed. Specifically, while oil shocks may be important to single markets, according to our results their effect on the stock markets of major oil consumer and producer countries is not as economically significant as it may be expected. Their effect is large only occasionally during periods of high financial turbulence. Meanwhile, shocks originating in global stock markets do have important effects on oil prices. This result provides additional support to the hypothesis of the financialization of oil markets.

We find that connectedness increased importantly around the global financial crisis, and remained in levels higher than those prevailing in the early 2000s until 2014. This result highlights that connectedness varies largely over time and tends to increase during times of financial distress. Although the importance of China is relatively small within the group of countries in our sample, its importance has increased since 2015. Importantly, it is the only country for which this behavior is identified. This result confirms that China is becoming a major participant in global financial markets.

Regarding causality, we find several interesting results. Looking from oil markets to stock markets, we encounter causal relations to all countries except Mexico. Causal relations are time-varying, and they are statistically significant only during short periods of time around the international financial crisis. With respect to the reverse causality, all stock markets Granger-cause oil prices during at least one period, except for India. Causality in this direction is stronger during times of financial volatility as well.

¹Our sample includes Mexico and Brazil (economies based in oil production), on the one hand, and China, India, the United States (US) and the United Kingdom (UK) (main oil consumers), on the other.

Our results have important implications both for investors and policy makers. For investors, we show that correlations between oil and stock markets vary over time, indicating that portfolio diversification strategies must be time-varying as well. Additionally, causality tests indicate that oil prices should not be considered exogenous to stock market developments. Hence, innovations affecting equity markets (and potentially other assets' markets as well) should be taken into account when predicting the future behavior of oil prices. Furthermore, we show that policy makers in oil-dependent economies should consider the strong interactions between oil and stock markets when designing policies for minimizing the negative effects of oil price shocks, specially during moments of financial turbulence. The remainder of the paper is organized in the following way. Section 2 presents a brief review of the related literature. The third section is methodological. Section 4 describes the data used in our empirical analysis. Section 5 presents our main findings and the last section concludes.

2 Brief literature review

The literature on the relation between oil prices and stock markets begins with Jones and Kaul (1996), who find that increases in oil prices negatively affect stock market returns in the US, the UK, Canada and Japan. This result is mainly driven by the effect of oil price shocks on firms' real cash flows. A vast amount of empirical papers testing for this relation have appeared thereafter, generating mixed results. Most of these papers assume that oil price shocks are exogenous and test their impact on stock market returns. The issue of reverse causation is ignored in these studies.

Country-specific studies on the impact of oil price innovations on stock markets are too numerous to be listed. Most of them find a negative impact of oil price increases on stock market returns (for instance, Sadorsky, 1999; Ciner, 2001; Pappetrou, 2001; Filis, 2010; Narayan et al., 2015). Similarly, several cross-country studies including both developed and developing economies have encountered similar results (e.g., Aloui et al., 2013; Cunado and Perez de Gracia, 2003). However,

some recent papers have shown that the nature of shocks and the heterogeneity of countries matters. Park and Ratti (2008) find that results are quite different for exporter and importer countries. Specifically, while stock market indices gain value after a positive shock in oil prices in the former, they depreciate in the latter. Meanwhile, Kilian and Park (2009) show that the response of US real stock returns to an oil price shock differs considerably depending on whether the change in the price of oil is driven by demand or supply shocks. Wang et al. (2013) finds results favoring the two previously mentioned studies. The paper shows that the magnitude, duration and direction of response by the stock market in a country to oil price shocks depends on whether the country is a net importer or exporter in the world oil market, and whether changes in oil price are driven by supply or demand shocks. Fang and Yu (2014) present similar findings.

All the studies mentioned above focus on the effects of oil price shocks on stock markets. Most of them assume that oil prices are weakly exogenous to stock market developments. However, papers on the financialization of oil markets argue that changes in the conditions of traditional financial markets can affect commodity markets, impacting spot commodity prices. Turhan et al. (2014), for example, shows that recently oil prices have been determined not only by aggregate supply and demand, but also by investment preferences and investors' behavior.

The oil financialization literature has motivated interest in the study of the direction of causality between crude oil prices and stock market returns. Papers in this strand have recently grown in number and many of them have detected bidirectional relations between oil prices and stock market returns (Arouri and Nguyen, 2010; Lee et al., 2012; Ajmi et al., 2014; Ding et al., 2016; Bouri et al., 2017).

Although many papers studying causality use information on stock markets of several countries, all of them focus in bivariate relations. In other words, they study independently causality between returns in each stock market and oil prices. Hence, these papers omit the increasing importance of interconnectedness and spillover effects in global financial markets (Gamba-Santamaria et al., 2017a). This issue is addressed by Zhang (2017), who uses the method developed by Diebold and Yilmaz (2012, 2014) to study interconnectness between oil prices and global

stock market returns within a multivariate framework. This study shows that the impact of oil price shocks on the world financial system is limited and varies significantly over time. Meanwhile, the reverse effect is of stronger magnitude. While this paper studies the issue of causality in a multivariate global context, it does not explore its potentially time-varying nature. Finally, Jammazi et al. (2017) explore the potential variation of causality over time, but within a bivariate context. We build on the literature above by studying the dynamic multivariate relation between oil prices and stock market returns and measuring connectiveness from a global perspective. We use the framework developed by Diebold and Yilmaz (2012, 2014) for appropriately addressing the issue of global interconnectedness, and test for bidirectional causal relations that may vary over time. We use the newly developed method of Hurn et al. (2016) and Clements et al. (2017) for doing so.

3 Methodology

Consider the following VAR(p) model

$$Y_t = \Phi_0 + \sum_{l=1}^p \Phi_l Y_{t-l} + \epsilon_t \quad (1)$$

where Y_t is a vector of size N , containing all stock market returns at time t , and $\epsilon_t | t-1 \sim F(0, H_t)$ where F is the multivariate conditional probability distribution of errors. H_t is the conditional covariance matrix of errors.

Our first step consists in computing different connectedness measures for the markets included in our sample. We follow Diebold and Yilmaz (2012, 2014), who present a method for computing market connectedness in a very general setup, flexible enough for allowing the calculation of pairwise and general connectedness indicators. These measures are based upon variance decompositions of vector autoregressions. Generalized variance decompositions following Pesaran and Shin (1998) are used, so results are invariant to the ordering of variables in the VAR model.

Regarding pairwise directional connectedness, market j 's contribution to market i 's H -step-ahead generalized forecast error variance² $\psi_{ij}^g(H)$ is calculated by

$$\psi_{ij}^g(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_i)} \quad , \quad H = 1, 2, \dots \quad (2)$$

where \sum stands for the covariance matrix of error vector ε , σ_{jj} is the standard deviation of the error term for the j^{th} equation, A_h is h^{th} -step moving average coefficient matrix and e_i is a extraction vector, i.e. a vector in which the i^{th} position is a one and the rest of entries are all zero.

In order to get well-defined percentages, i.e. numbers between 0 and 1, $\psi_{ij}^g(H)$ can be normalized in the following way:

$$\psi_{ij}^{-g}(H) = \frac{\psi_{ij}^g(H)}{\sum_{j=1}^N \psi_{ij}^g(H)} \quad (3)$$

where $\sum_{j=1}^N \psi_{ij}^g(H) = 1$ and $\sum_{i,j=1}^N \psi_{ij}^g(H) = N$ by construction. $\psi_{ij}^{-g}(H)$ is the indicator of pairwise connectedness from market j to market i . Directional connectedness is being measured by $\psi_{ij}^{-g}(H)$. Hence, we do not assume symmetry, i.e. $\psi_{ij}^{-g}(H) \neq \psi_{ji}^{-g}(H)$, for $i \neq j$. In words, the effect of market j on market i is not identical to the effect of market i on market j .

After computing pairwise connectedness measures for every possible pair of markets, several different indicators of systemic connectedness can be computed. Three important systemic measures arise. First, a measure of connectedness from others to market i can be computed as $\sum_{j \neq i} \psi_{ij}^{-g}(H)$. Second, a measure of connectedness from market i to the other markets, given by $\sum_{j \neq i} \psi_{ji}^{-g}(H)$. The net position of mar-

²In our empirical analysis we focus on a ten-day horizon, but our results are qualitatively identical for different horizons, from 5 to 10.

ket i is calculated as the difference of these two gross positions with respect to the rest of the system. And, finally, the total connectedness index of the system can be computed as

$$\frac{1}{N} \sum_{i, i \neq j} \psi_{ij}^{-g}(H) \quad (4)$$

This measure of total connectedness as is simply the average of all the total directional connectedness measures whether they are "to" or "from".

After computing the different connectedness measures, we go one step forward and compute dynamic Granger causality tests between pairs of market returns. We follow the method of Hurn et al. (2016) who develop a test for detecting changes in causal relationships based on a recursive rolling window.³ The test has three advantages over others. The principal is that the VAR model accounts for potential endogeneity issues overlooked by the traditional framework. Specially relevant, it accounts for endogeneity issues between cross-sectional return dispersion and market volatility. Additionally, the test involves a rolling window algorithm that enables endogenous dating of the change points in the predictive relationship. Hence, if causality is detected, its sign (positive or negative is identified) as well as its intensity. Finally, the testing framework considers the potential heteroskedasticity of the data, reducing the chance of flawed inference.

4 Data description

Our data set consists of daily closing prices of crude oil and the stock market indices of six major oil market participants, namely Brazil, China, India, Mexico, the UK and the US. Stock market returns are calculated as the first difference of logarithmic stock market prices. All data was collected from Bloomberg, and the following indices were used: the WTI (expressed in US dollars per barrel), the BOVESPA (Brazil), the SHCOMP (China), SENSEX (India), MEXBOL (Mexico), FTSE100 (the UK) and the S&P500 (the US). Given our interest in causality, and in order to avoid unnecessary noise in the data, we use our data with monthly fre-

³For details in the test of causality employed in this study, please refer to Hurn et al. (2016).

quency in our empirical analysis. Our sample spans the period comprised between January 2000 and April 2017, allowing us to assess the effect of the recent international financial crisis on the dynamic interactions between oil prices and stock market returns.

Table 1 presents descriptive statistics of our data. Notice that the returns of the WTI and those of the six stock market indices included in our sample are stationary, according to ADF unit root tests. All means are positive but skewness is negative in all cases. Hence, negative returns are more frequently observed than positive returns in our sample. Kurtosis is higher than 3 for all returns, and results from Jarque-Bera tests (not reported in the table) indicate that the normal distribution is not adequate for our data.

Table 1. Descriptive statistics on the WTI and stock market returns

	Mean	Std. Dev	Skewness	Kurtosis	ADF test
SP500	0.002	0.04	-0.74	4.57	-12,78***
FTSE100	0.0004	0.03	-0.68	3.81	-14,45***
SHCOMP	0.003	0.07	-0.55	4.62	-12,75***
SENSEX	0.008	0.06	-0.47	4.66	-13,25***
MEXBOL	0.009	0.05	-0.49	4.15	-13,40***
BOVESPA	0.006	0.07	-0.39	3.6	-12,71***
WTI	0.003	0.09	-0.56	4.08	-12,11***

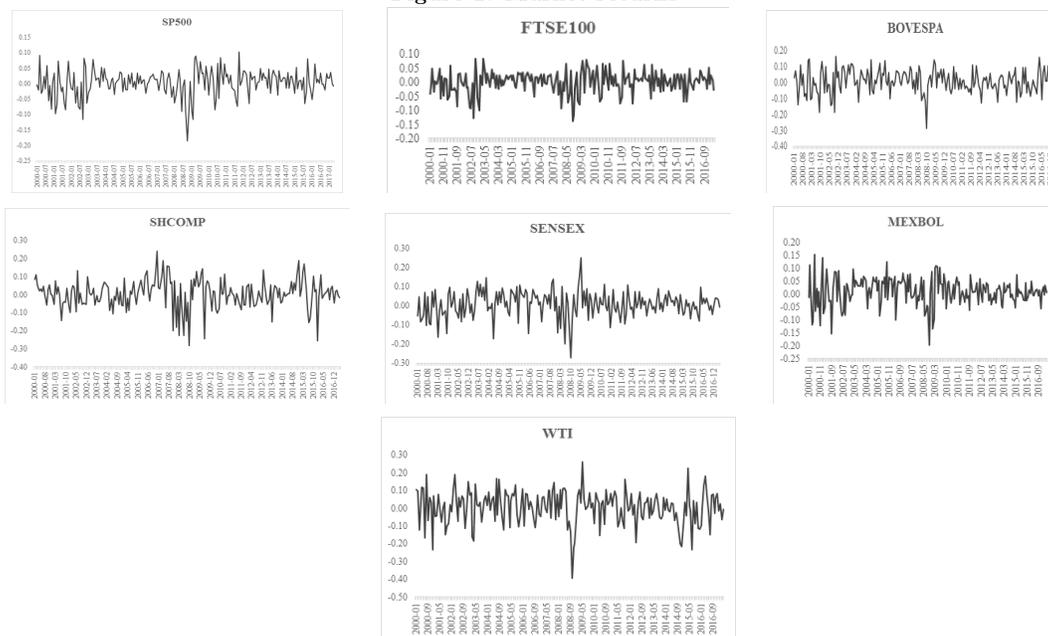
Note: *** denotes 1% level of significance. Lag selection in ADF test is based on Bayesian Information Criteria (BIC)

Figure 1 depicts the behavior of returns over time. Notice that in all cases returns were substantially lower and presented higher variance around the Lehman Brothers' failure in September 2008. Table 2 shows unconditional Pearson's correlation coefficients between pairs of returns. It can be seen that the minimum correlations occur within pairs of returns including either the WTI or the SHCOMP. The highest correlation, as expected, is registered between the two main stock market returns, namely the S&P500 and the FTSE100. Although these preliminary results appear to be intuitive and appealing, it is important to remember that unconditional correlations in this context present the serious limitation of being time-invariant.

Table 2: Correlation coefficients

	S&P500	FTSE100	SHCOMP	SENSEX	MEXBOL	BOVESPA	WTI
S&P500	1						
FTSE100	0.8457	1					
SHCOMP	0.3088	0.2449	1				
SENSEX	0.5617	0.5492	0.306	1			
MEXBOL	0.6704	0.5924	0.2316	0.5572	1		
BOVESPA	0.6597	0.6282	0.3583	0.595	0.6653	1	
WTI	0.256	0.2332	0.2268	0.3238	0.2687	0.2857	1

Figure 1: Market returns



5 Results

Table 3 presents connectedness results for the full sample. The total connectedness in our system is of 56.0%. This indicates that the indices selected in this study are highly interconnected and represent an important share of world's financial

system.⁴ The ij^{th} entry of the table shows the contribution of the j^{th} index return to the relation with the i^{th} index return. For instance, entry (2, 3) in the table shows a value of 0.045. This value corresponds to the connection spillover from the FTSE100 to the SHCOMP. The last entry in each column, labeled "To", presents results of total connectedness from the market index corresponding to that column to the rest of markets. The column labeled "From" shows results of connectedness from the market in each row to the rest.

The last column of the table, labeled *NDC* (net directional connectedness), shows the net position of each index return to global connectedness. A positive (negative) sign indicates a net positive (negative) contribution of the corresponding index return to total connectedness. The net contribution of return i is calculated as the difference between the total spillover given by return i and the total spillover it receives from the rest of returns in the sample. Our results show that the US, the UK and Brazil are the main contributors to connectedness, as they exhibit the highest (positive) net positions. The result for Brazil is interesting and shows that this country's financial markets are not only prominent in the Latin American region, but also play an important role in global markets.

Table 3: Connectedness (full sample)

	SP500	FTSE100	SHCOMP	SENSEX	MEXBOL	BOVESPA	WTI	From	NDC
SP500	N/A	0.241	0.035	0.101	0.140	0.144	0.019	0.680	0.129
FTSE100	0.247	N/A	0.025	0.101	0.125	0.147	0.027	0.671	0.112
SHCOMP	0.059	0.045	N/A	0.068	0.031	0.089	0.033	0.327	-0.131
SENSEX	0.131	0.126	0.039	N/A	0.121	0.153	0.040	0.610	-0.024
MEXBOL	0.162	0.144	0.024	0.117	N/A	0.170	0.023	0.641	-0.026
BOVESPA	0.150	0.156	0.043	0.128	0.152	N/A	0.026	0.655	0.126
WTI	0.060	0.071	0.029	0.072	0.046	0.077	N/A	0.355	-0.186
To	0.809	0.783	0.196	0.586	0.615	0.781	0.169	0.56	

Important to note, oil prices receive more than what they contribute to global connectedness, and hence their net position is negative (-18.6%). In fact, they present the largest negative position. This finding challenges the conventional view that treats oil prices as exogenous in their relation with financial markets and justifies testing for bidirectional causality in studies involving oil prices and stock market

⁴Total connectedness measures in related studies are lower than the one encountered in this study. See, for instance, Gamba-Santamaria et al. (2017a, 2017b) and Zhang (2017).

indices. 0

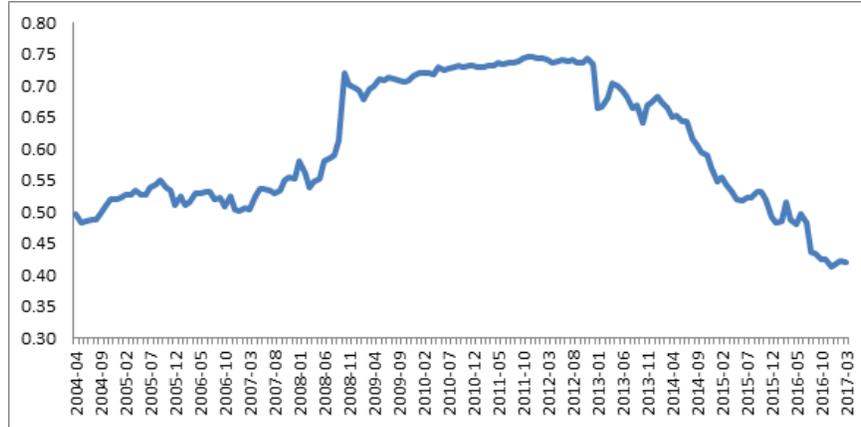
Our results show that China is a net receiver (13.1%). This result goes in line with Gamba-Santamaria et al. (2017b), who find that while the importance of China in international financial markets has increased over the last years, this country is still a net receptor of volatility from the world's major financial markets.

Although results shown in Table 3 are interesting, as they present a snapshot of what happened in global markets for the whole sample period, they do not allow checking whether connectedness within markets changes over time. Of special relevance, several papers have shown that market relations that appeared to be stable during decades changed during the recent global financial crisis and in its aftermath (see, for instance, Borio et al., 2016, and Ordoñez-Callamand et al., 2017). Hence, it is interesting to test whether connectedness exhibits time-variation over our sample period. In order to account for that possibility, we use a rolling-window approach, following Diebold and Yilmaz (2012, 2014). Our full sample has 196 time-observations for each index return. We use a window size of 49, exactly 25% of the full sample size.

Figure 2 shows the dynamic behavior of connectedness for our sample period. Note that total connectedness varies largely over time, ranging from a minimum value of 41.7% in December, 2016 to a maximum of 74.7% in November, 2011. This maximum value coincided with the peak of the European sovereign bond crisis. The major jump in this indicator occurred between August, 2008 (59.0%) and October 2008 (72.1%). This jump took place around the failure of Lehman Brothers. Hence, our results confirm those of other studies indicating that market interconnectedness and volatility spillovers tend to be higher during periods of financial

markets turbulence.

Figure 2: Rolling-windows estimation of total connectedness



We mentioned above that the WTI has a negative net position in the interconnect-
 edness measure. However, this does not mean that it is always a net receiver from
 the system. Figure 3 shows that at the beginning of the 2000s it was a small net
 transmitter. However, this position changed and became negative around 2005.
 Note that in 2008, in the midst of the subprime financial crisis, the gross transmis-
 sion from stock markets to oil prices largely increased, making the WTI a large net
 receptor. In the aftermath of the financial crisis this transmission was reduced but
 oil continued to be a net receptor.

Figure 3: Contribution to, reception from, and net position. WTI

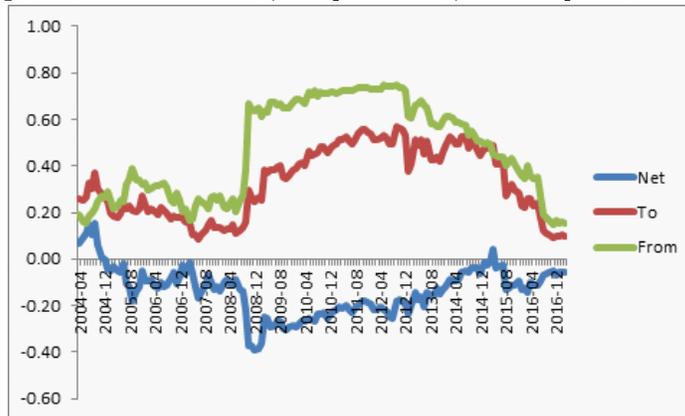


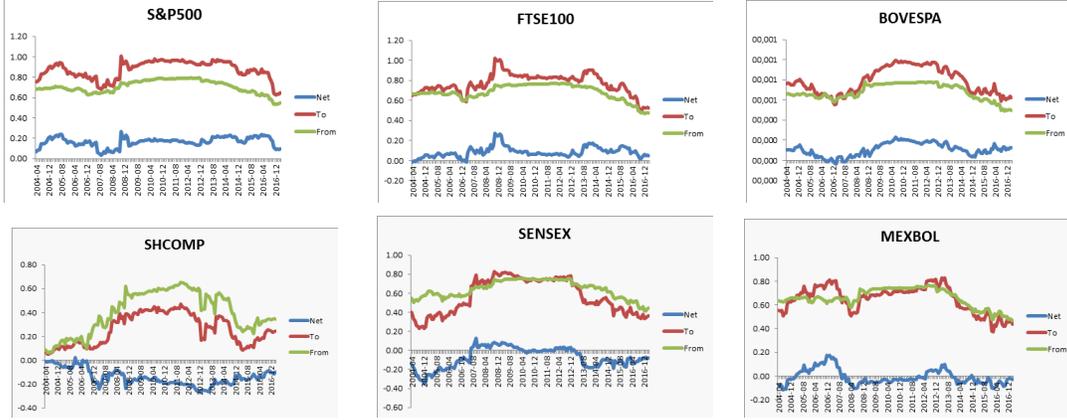
Figure 4 shows gross transmission, gross reception and the resulting net position for the six stock markets included in our sample. The gross position of all six stock markets is relatively large both in transmission and reception. Hence, they are important players in international financial markets.

The top three panels of Figure 4 show graphs for the US, the UK and Brazil. Notice that in all three cases, while time-variation exists, the stock markets of these countries are always net transmitters to the system (except for very short periods of time in the cases of the UK and Brazil). This fact highlights the importance of these three stock markets in the world's financial system. Worthy to mention, Brazil plays a role of major importance not only regionally, but also globally.

Mexico was a net transmitter during the first few years of the sample. However, similar to the WTI, its position changed at the beginning of the subprime financial crisis and since then it has been a net receiver. On the contrary, India was a net transmitter during the period of the financial crises in the US and Europe. At the end of the sample it returned to a net receiver position of similar magnitude to the one prevailing before 2007. China has been always a net receiver, but during the last two years it has been the only country in the sample that has increased both gross positions systematically and considerably. Another interesting fact for China is that during the global financial crisis the spread between its gross receiver position and its gross transmitter position was larger than for the rest of countries in the sample. Hence, China's was the most affected stock market during the recent

financial crisis within the set of six countries studied in our paper.

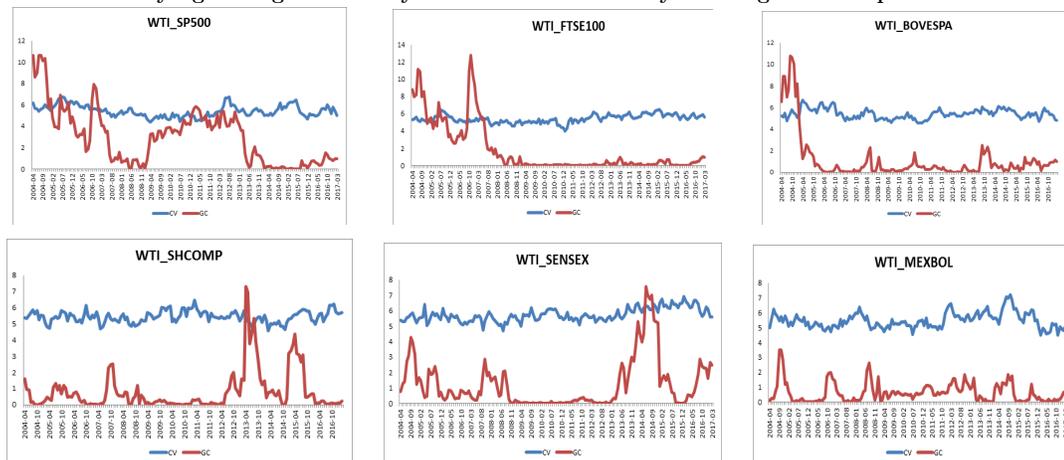
Figure 4: Contribution to, reception from, and net position. Stock market indices



Up to now we have reported results on interconnectedness between markets. However, an interesting question deals with causality. Considering the hypothesis of the financialization of oil, it is worthy to study the potential bidirectional causality between oil prices and stock market returns. Below we report our main findings using the time-varying Granger causality test described in the methodological section of this paper.

We report results in two stages. First we show our findings regarding causality from oil prices to each of the six stock markets. In each case we perform our tests in a multivariate framework in which all included variables are allowed to be endogenous. Figure 5 depicts these results. In each panel the graph denoted "CV" presents the critical value of the test at the 95% significance level. The graph denoted "GC" shows the value of the test statistic. Granger causality from oil prices to the corresponding stock market is detected whenever GC lies above CV at a point in time, i.e. when the value of the test statistic is larger than the critical value at the 95% significance level.

Figure 5: Time-varying Granger causality test results. Causality running from oil prices to stock markets

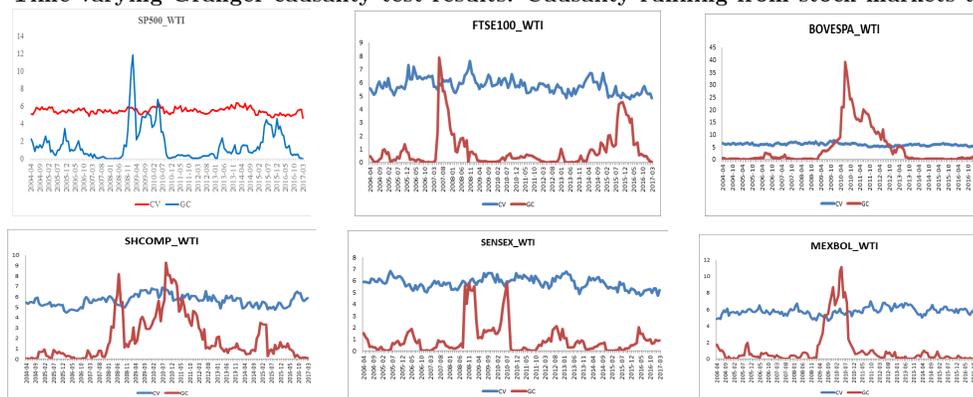


Important to note, in all cases except for Mexico, the WTI Granger causes the respective stock market in at least one month. The fact that for Mexico causality is never detected is interesting taking into account that the Mexican economy relies heavily in oil crude production. The reason behind this result is probably due to the existence of an oil price stabilization fund in Mexico, that has the objective of isolating the Mexican economy from short-run oscillations in crude petroleum oil price shocks. Our results provide evidence suggesting that this fund has been effective in its goal regarding the stock market.

The top three panels of Figure 5 show results on causality tests for the three stock markets that are the most important connectedness transmitters. Interesting to note, causality from oil prices to these three stock markets is only detected in short periods of time before the recent international financial crisis. This results strengthen our findings reported above showing that during the crisis and in its aftermath contagion has occurred more from the major stock markets to oil prices than viceversa. These findings also further support the hypothesis of the financialization of oil markets. Meanwhile, causality from the WTI to the stock markets of China and India is only detected for short periods of time after the subprime financial crisis. Figure 6 show results regarding reverse causality, i.e. from stock markets to crude

petroleum prices. Note that, according to our test results, all markets (except India) Granger-cause the price of oil at some moment of time, supporting the hypothesis of oil financialization. Causality is strongest during the financial crises in the US and Europe. As suggested in Gkanoutas-Leventis and Nesvetailova (2015), this may obey to the fact that during these crises capitals flew from several stock markets to commodity markets. This flight was due (and also contributed to) the depreciation of equity prices and the appreciation of commodity prices. Importantly, Brazil and Mexico Granger cause the WTI for the longest periods of time. This illustrates the relevance of these two Latin American markets in global financial markets.

Figure 6: Time-varying Granger causality test results. Causality running from stock markets to oil prices



6 Conclusions

In this paper we study the relation between oil prices and stock market returns for a set of six countries, including important oil consumers and demanders. While most studies in this field take oil prices as exogenous and focus on the effects of oil price shocks on stock market indices, we allow them to be endogenous in our system. Using the method developed by Diebold and Yilmaz (2012, 2014), we study interconnectedness between oil and stock markets, and characterize the dynamics of transmission and reception between them. Furthermore, we test for Granger causality between markets dynamically, endogenously identifying periods for which

oil prices have responded to innovations in financial markets.

Our contributions to the literature are three-folded. First, we uncover the dynamic multivariate relation between oil prices and stock market returns and measure connectiveness from a global perspective. Concretely, we compute both total and directional connectedness using forecast error variance decomposition from vector autoregressions. Second, we are the first study to implement this approach for a set of countries including both developed and emerging economies. And, third, we study causality between oil prices and stock market returns, following the recently developed method proposed by Hurn et al. (2016). Using this method we are able to study endogenous changes in causality over time, with the advantage of admitting bidirectional relationships.

Our results on connectiveness show that transmission mainly flows from stock markets to crude petroleum prices. Specifically, while oil shocks may be important to single markets, their effect on major stock markets as a whole is not as economically significant as it is sometimes assumed. Their effect is large only occasionally during periods of high financial turbulence. Meanwhile, shocks originating in global stock markets do have important effects on oil prices. This result supports the hypothesis of oil markets' financialization.

We find that connectedness increased importantly around the global financial crisis, and reported high levels until 2014. Although China's contribution to connectedness is of minor importance within the countries included in this study, its relevance has been increasing since 2015, being the only country for which this behavior is identified. This result confirms that China is becoming a major participant in global financial markets.

Regarding causality, we find several interesting results. We encounter causal relations from crude petroleum to all countries except Mexico. These relations are time-varying, and causality is only statistically significant during short periods of time. With respect to the reverse causality, all stock markets Granger-cause oil prices during at least one period, except for India. Causality in this direction is stronger during times of financial volatility as well.

Our results have important implications both for investors and policy makers. For

investors, we show that correlations between oil and stock markets vary over time. This indicates that the design of portfolio diversification strategies must change over time as well, considering the stage of the global financial cycle. Additionally, causality tests indicate that oil prices should be considered endogenous to stock market developments. Hence, innovations affecting equity markets should be taken into account when predicting the future behavior of oil prices. Furthermore, we show that policy makers in oil-dependent economies must consider the strong interactions between oil and stock markets when designing policies for minimizing the negative effects of oil price shocks, specially during moments of financial turbulence.

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